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ABILITY FACTORS AND COMPONENT PERFORMANCE MEASURES AS PREDICTORS OF COMPLEX TRACKING BEHAVIOR[1]

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THE present study investigates the relationships between ability variables and progress in learning a complex perceptual-motor skill. It represents an extension of previous research in which ability patterns at early and advanced performance levels in psychomotor tasks have been compared with a view to establishing the kinds of abilities and measures most predictive of higher levels of proficiency. These studies have implications for questions concerning the processes involved in learning complex skills as well as for problems in training and test development.

The distinction between the terms "ability" and "skill" as used here should be made explicit. The term ability refers to a more general, stable trait of the individual which may facilitate performance in a variety of different tasks. Thus, the ability of spatial-visualization may be important in such diverse activities as navigation, dentistry, and engineering. The term skill is more specific: it is task oriented. Flying an airplane is a skill, while manual dexterity and spatial-visualization are more general abilities. Of course, abilities themselves are often products of earlier learning. This view is elaborated elsewhere (Gagné & Fleishman, 1959).

It has been found that for certain classes of perceptual-motor tasks, there are progressive qualitative and quantitative changes in those abilities which contribute to proficiency as the task is learned. This has been demonstrated with a serial reaction task (Fleishman & Hempel, 1954a), a visual discrimination reaction task (Fleishman & Hempel, 1955), and a continuous pursuit task (Fleishman, 1956). Woodrow (1938) has found the same progressive changes to be involved in extended performance on printed tests. In other words, for those tasks proficiency at later stages of learning depended upon different combinations of abilities than did initial proficiency.

The present investigation differs from others in this area in two major respects. First, the task is considerably more complex than that used in previous studies. In the present instance the task roughly simulated that performed by a pilot during the attack phase of an airborne radar intercept mission. Thus, the task was more "realistic" and more demanding than the labora-

[1] This study was initiated in 1956 under Air Force Contract AF 41(657)-64 between Psychological Research Associates, Inc. and Air Force Personnel and Training Research Center. In 1958 cognizance of this contract was transferred to the Aero Medical Laboratory, Wright Air Development Center. Edwin A. Fleishman served as Project Monitor while a member of the Skill Components Research Laboratory of Air Force Personnel and Training Research Center. He retained his association with the project while on the faculty of Yale University. Robert A. Seibel, Bryce O. Hartman, and Marty R. Rockway served as project monitors during the latter stages of the study.

The correlation analysis and factor analysis procedures were accomplished under terms of a subcontract with Psychological Research Service, Inc. of Austin, Texas. They were directed by Benjamin Fruchter.

The tracking devices and scoring consoles were designed by Henry P. Birmingham of the Naval Research Laboratory.

tory tests previously investigated. The second difference involved the total amount of learning time which was investigated. A limitation of previous studies has been the relatively short period required to achieve a high level of proficiency. In the present study subjects were trained for 17 sessions distributed over 1 to 1.5 months.

The increased complexity of the present task raises the question of whether new kinds of abilities are required and whether the patterning of these abilities is different from that found with previous tasks. For example, the introduction of complexity of function may demand certain skills of integration and coordination not previously required.

A primary purpose of this study, as stated above, was to specify the abilities underlying terminal proficiency on a complex control task and to identify the manner in which the contribution of these abilities to proficiency changes during the course of learning. Another important objective was to compare the predictability of terminal performance from external measures with predictions from measures taken earlier in practice on the task itself. In a previous study (Fleishman & Hempel, 1954a) it was found that advanced performance on a psychomotor task, the Complex Coordination Test, was better predicted from a combination of printed and apparatus tests than from early scores taken on the task itself. This study presented an opportunity to test the generality of this finding in a more complex task situation.

Procedures

Data Gathering

The experimental procedures followed in this study are similar to those used in previous studies in this series. Subjects were first administered a large reference battery of printed and psychomotor apparatus tests. Following this the same subjects spent a number of sessions mastering the criterion task. Performance measures were taken at the various stages of practice on this task. Correlations among scores on both the reference battery and the stages of learning of the criterion task were obtained and factor techniques applied. The factors were defined from the loadings of the reference tests. Loadings of the various stages of practice of the criterion task on the factors defined by the reference tests specify the changes in the factor pattern of this task as practice continues.

Subjects

The subjects were 203 freshman and sophomore Air Force ROTC students at the University of Maryland. No subject had had pilot training of any kind. Each subject was paid for his participation in this study.

Reference Battery

The initial testing consisted of the administration of a large battery of psychomotor apparatus and printed tests. Initially a listing was made of those factors which might be of importance in mastering a complex tracking task. This list even included such abilities as "Verbal Comprehension," inasmuch as this ability might be of importance in understanding the explanation of the requirements of the task and thus be involved in determining ultimate proficiency. The majority of the reference tests were selected in terms of their factor loadings on these abilities in previous investigations. A complete listing of the hypothesized ability factors and the loadings of the various tests on these factors is presented in Appendix A. The test battery consisted of 23 apparatus and 21 printed tests. Fifty different scores were provided by this battery.

Total time for the administration of this battery was 11 hours. This was divided into three 2-hour sessions for the administration of the printed tests and five 1-hour sessions for the administration of the apparatus tests. Two models of each apparatus test allowed for the testing of subjects in pairs. A complete listing of the tests comprising the reference battery is presented in Table 1. This table also presents reliability coefficients for each test in the battery. Appendix B presents drawings of the apparatus tests and descriptions of all tests, both printed and apparatus.

Criterion Task

Subject Task. The criterion task consisted of a tracing device constructed so as to simulate roughly the display characteristics and control requirements of an airborne radar intercept mission. The task of the subject was to maintain the target dot at the center of the oscillograph display, while at the same time nulling a sideslip indicator. That is, the subject envisoned himself to be flying the attack phase of an airborne radar intercept mission. Thus, if the target was to the right, the subject made appropriate control movements to steer the craft to the right. These movements would bring him "on target" and the dot would return to the center of the display. All turning

TABLE 1

PRINTED AND APPARATUS TESTS COMPRISING REFERENCE BATTERY

Test	Test Reliability[a]
Printed	
1. Aerial Orientation	.84
2. Complex Movements	.85
3. Coordinate Movements	.70
4. Directional Control	.85
5. Discrimination Reaction Time	.87
6. Following Directions	.75
7. Forced Landings	.88–.91
8. Formation Visualization	.76
9. General Mechanics	.88
10. Instrument Comprehension	.92
11. Mechanical Comprehension	.82
12. Pattern Comprehension	.76
13. Planning a Course	.81
14. Signal Interpretation	.77
15. Spatial Orientation	.69
16. Speed of Identification	.74
17. Stick and Rudder Orientation	.74
18. Verbal Comprehension (Vocabulary)	.90
(50) Verbal Comprehension (Background for Current Affairs)	.87
19. Visual Pursuit	.80
20. Visualization of Maneuvers	.87
Apparatus	
21. O'Connor Finger Dexterity	.76
22. Purdue Pegboard (Summation Score)	.90[b]
23. Minnesota Rate of Manipulation (Placing)	.87
24. Minnesota Rate of Manipulation (Turning)	.79
25. Two-Plate Tapping	.99
26. Precision Steadiness (Errors)	.90
27. Direction Control (Corrects)	.90–.95
28. Control Sensitivity	.94[c]
29. Ten Target Aiming (Errors)	.94
30. Ten Target Aiming (Corrects)	.91
31. Bimanual Matching	.74[c]
32. Track Tracing (Errors)	.91
33. Two-Hand Coordination	.89–.93[a]
34. Choice Reaction Time	.68[c]
35. Complex Coordinator	.85–.95
36. Pursuit Confusion (Errors)	.90
37. Pursuit Confusion (Corrects)	.88
38. Motor Judgment	.56[c]
39. Discrimination Reaction Time	.87–.96
40. Rotary Pursuit	.92–.97
41. Visual Reaction Time	.86
42. Auditory Reaction Time	.85
43. Jump Visual Reaction Time	.88
44. Jump Auditory Reaction Time	.88
45. Steadiness Aiming	.84
46. Single-Dimension Pursuit	.84–.92
47. Rate Control	.89
48. Rotary Aiming	.96
49. Rudder Control	.90–.92

[a] Reliabilities for those tests not computed directly from data of this study are taken from the following: Fleishman (1958b) Guilford and Lacey (1947), Roff (1951).

[b] Based on average reliability of the four subparts of this test and corrected for an increase in length by a factor of four.

[c] Computed using data of this study (split-half).

movements required coordinated action of stick and rudder controls.

Three identical tracking devices were constructed especially for purposes of this study and are shown in Figures 1 and 2. A block diagram[2] is presented in Appendix C. These devices and related scoring consoles allowed for the testing of from one to three subjects simultaneously under the control of a single test administrator.

[2] Complete schematics of all components are presented in *Wright Air Development Center Report* TR 59-255.

FIG. 1. Photograph of tracking facility showing three tracking devices, computer programer, and scoring console.

FIG. 2. Photograph of tracking device.

Each subject was given a brief indoctrination into the nature of the task and the action of the control system. He was then allowed 5 to 10 seconds of practice. Following this, through the remainder of the training program, there was no formal guidance of any sort. Each subject learned the task on his own. However, all questions of subjects related to the operation of the system were answered. Each subject was told his integrated error score following every trial.

Displays. The subject's instrument panel contained two displays. The first consisted of a target dot presented on a cathode ray oscillograph. The target course was generated by setting the equation of a swinging pendulum into an analog computer. This produced a sine wave with a frequency of approximately 6 cycles per minute in the horizontal coordinate as the target course. The rate of decay in amplitude was approximately 5% per cycle. However, the dynamic characteristics of the over-all task were such that subjects neither perceived this drop in amplitude nor the fact that the target was programed in one coordinate only. Any control imbalances resulted in dot excursions of considerably larger magnitude than those provided by target programing.

Beneath the oscillograph was an inverted 3-inch, zero-centered voltmeter termed a "sideslip indicator." This meter reading indicated to the subject a "lack of coordination" in control actions when centering the target dot. This indicator did not constitute an independent task but rather provided the subject with additional information related to the primary task.

Control System. In performing this task subjects used a standard aircraft control system involving a control stick and rudder pedals. These controls were coupled in a manner similar to those of an actual aircraft. Thus, application of right control stick pressure without proper amount of right rudder produced a sideslip to the left and a consequent left deflection on the sideslip indicator.

Control of the target dot in elevation was accomplished by forward and backward movements of the control stick. This was a pure second-order system resulting from the use of two cascaded integrators in the linkage between the control and display. Thus the acceleration of the target dot was directly proportional to stick displacement.

Control of the target dot in azimuth was accomplished by right and left movements of the control stick. This comprised a system involving acceleration control plus an exponential lag network. This dimension was mechanized using three cascaded integrators with a negative feedback loop around one. The time constant of this lag network is 1 second; that is, it requires 1 second to achieve approximately two-thirds ($1\text{-}1/e$) of the final signal resulting from a given stick displacement.

Control of the target dot in azimuth (envisoned as turning the aircraft) and centering the sideslip indicator (coordination display) were both effected by rudder pedal displacement as well as

by the control stick. This rudder control of the sideslip indicator involves a simple lag network. Thus, the sideslip indicator displacement was directly proportional to rudder pedal displacement. Movement of the sideslip indicator by stick action represents a velocity control operating through two exponential lag networks.

Movement of the target dot by rudder pedal displacement approximates a pure velocity control.

Criterion Scores. The following five performance measures were obtained during each testing session. Four of these were error scores; one was a time-on-target score. The error scores represent the extent of target dot (or indicator needle) displacement from the null position in one dimension summated through time.

1. Integrated absolute error score. This was recorded at the conclusion of every trial and was produced by summing algebraically the three absolute error part scores described below in accordance with this relationship:

$$T = 1/2X + 1/2Y + Z \qquad [1]$$

Where T = Integrated absolute error score
X = Absolute azimuth error
Y = Absolute elevation error
Z = Sideslip error

The double weight for the sideslip error was introduced on the basis of pretest results in which it was noted that some subjects neglected rudder pedals altogether and used only the stick to control the dot. The increased weight made a good total score more dependent upon proper rudder pedal use.

Each of the following part scores was recorded every third trial. An automatic sequencing mechanism switched from one part score to the next at the conclusion of each trial.

2. Azimuth (yaw) part score. This is a summation of the total error occurring in the horizontal axis of the oscillograph display.

3. Elevation (pitch) part score. This is a summation of the total error occurring in the vertical axis of the display.

4. Sideslip error part score. This is a measure of the lack of coordination between stick and rudder movements.

5. Time-on-target score. This score represents the time during the trial when the target dot and the sideslip indicator needle are both (simultaneously) within prescribed tolerance limits.

The time-on-target area consisted of a diamond-shaped area (a tilted square) in the center of the oscillograph. This area was not demarked for benefit of the subject. Distance from the center of the oscillograph to any corner of the square was 1 inch. Sideslip error also entered into the calculation of time-on-target. Sideslip tolerance was ± 0.5-inch needle displacement from center. Thus, if a subject approached the tolerance limit in the X axis of the scope display, a slight deflection of the sideslip indicator would throw him out of tolerance.

Data Analysis

Reference Test Scores

From each test, the obtained distributions of raw scores were transformed to normalized distributions of standard scores (stanines), each with a range from 1 to 9, a mean of 5, and a standard deviation of 2. Conversions were made so that the 9 end of the scale was always indicative of good performance.

Tracking Performance

Each of the 17 practice sessions for the criterion tracking task consisted of 21 1-minute trials, making a total of 357 trials.

The problem of deciding on the size of the time segment to be sampled from these trials involved the following considerations. It was necessary to have each segment large enough to be sufficiently reliable; at the same time, it was desired to keep the segment small enough to provide

TABLE 2

RELIABILITIES OF THE VARIOUS MEASURES OF TRACKING PERFORMANCE AT THREE STAGES DURING THE LEARNING PERIOD

	Integrated Error	Horizontal Error	Vertical Error	Sideslip Error	Time-on-Target
Early Stage (Segment 1–Segment 2)	.83	.64	.60	.63	.58
Intermediate Stage (Segment 25–Segment 26)	.87	.67	.68	.87	.78
Final Stage (Segment 50–Segment 51)	.89	.56	.67	.96	.89

Note.—All correlations based on 203 cases.

as precise as possible a definition of the learning curve. Thus, use of an entire session as a segment might be highly reliable but changes occurring during the session might be obscured.

For each session, scores of the first three trials were discarded in order to avoid problems of warm-up effect. The remaining 18 trials of each session were then subdivided into three groups of six trials each. Each group of six trials was designated "time segment" of performance. There were thus 51 time segments obtained through the full period of practice. For each of the over-all measures of performance (integrated error score and time-on-target score) one time segment represents 6 minutes of performance. For each of the part scores (elevation, azimuth, and sideslip error), a time segment represents 2 minutes of performance, a part score being recorded on every third trial only. Table 2 presents reliability coefficients for each measure of performance at an initial, intermediate, and terminal stage of learning. These coefficients represent the correlation of adjacent time segments.

Learning Curves. Figures 3 through 7 present the learning curves for the five measures of tracking performance. All error learning curves are similar except that shown in Figure 7 for sideslip (coordination) error. This error curve shows little improvement until about Segment 15. This reflects the fact that many subjects did not use the rudder pedals to any great extent during initial practice sessions. It appears that although subjects understand the requirements of this task, they will not attempt to time-share stick and rudder controls until they have attained some skill in using the stick control. The time-on-target curve differs from the others in that it is sigmoidal rather than exponential. This is because the time-on-target represents a poor measure of performance at the extremes when the subject either is continuously out of or continuously in tolerance. The error scores do not suffer in this respect.

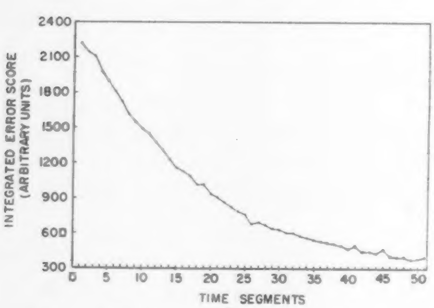

FIG. 3. Performance curve based on integrated absolute error measure.

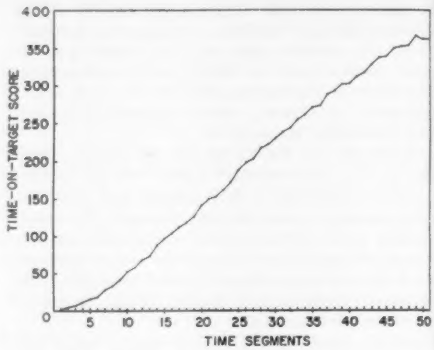

FIG. 4. Performance curve based on time-on-target measure.

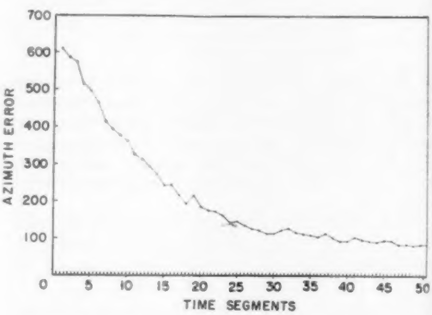

FIG. 5. Performance curve based on azimuth error measure.

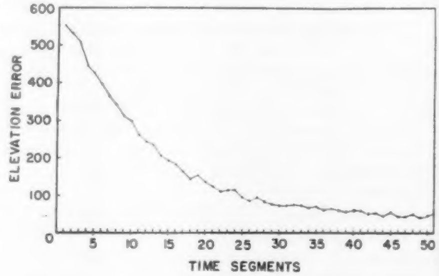

FIG. 6. Performance curve based on elevation error measure.

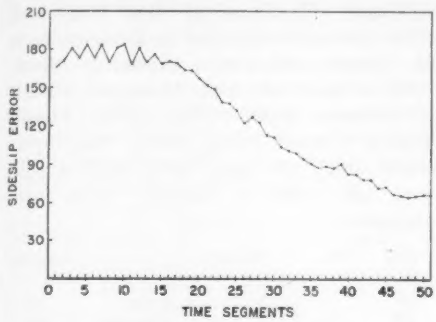

FIG. 7. Performance curve based on sideslip (coordination) error measure.

Figures 3 through 7 illustrate group performance and present relatively stable curves. There was, however, considerable variation among individuals with respect to performance on this task. Figure 8 presents performance curves based on integrated error score for three subjects. These curves were selected to illustrate the extent of individual differences both in rate of learning and in terminal proficiency. Subject A, for example, is the poorest initially but rapidly improves to a high level of proficiency. Subject B improves slowly and erratically throughout the period of practice, although initially he is better than Subject A. Subject C shows relatively little improvement at any time.

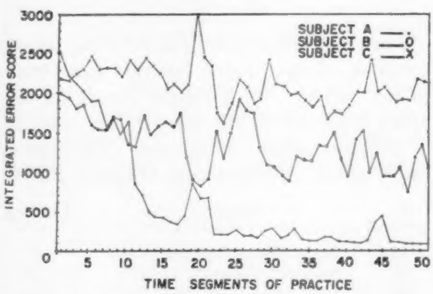

FIG. 8. Curves of three selected subjects illustrating the extent of individual variation in performance.

Selection of Practice Stages for Factor Analysis. It was decided that 10 stages of practice would be used in the subsequent factor analysis as a basis for determining the changes in underlying ability patterns during the learning of this task. The selection of the appropriate 10 stages of practice was accomplished before it was possible to compute the mean scores for the entire sample of 203 subjects. For this purpose data from a random sample of 25 subjects were chosen, and a curve using integrated error score as a measure of performance was generated. Figure 9 presents this curve and indicates the 10 stages of practice which were selected for inclusion in the final data analyses. Points were selected in a manner it was felt would maximally define critical periods during the learning process. All performance measures at each of these 10 practice stages next were converted into stanine form for further analyses.

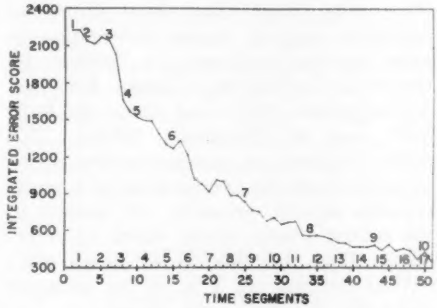

FIG. 9. Curve based on integrated error score of 25 randomly selected subjects showing selection of 10 stages of performance.

Correlational Analyses

Following the transformation of all reference test scores and criterion measures into stanine form, subsequent data analyses were accomplished through use of the ORDVAC high-speed digital computer. Appendix D presents the matrix of intercorrelations among all printed and apparatus tests of the reference battery. Appendix E presents intercorrelations between reference tests and performance measures of the tracking task. Appendix F presents intercorrelations between and within total scores and component scores taken from the task itself.

The matrix of intercorrelations of reference tests was factor analyzed using a digital computer program yielding a principal axes solution. Fifteen factors were extracted by this method. Appendix G presents the unrotated factor loadings for tests in the reference battery. Orthogonal rotations of the reference axes were made, using the graphical method of Zimmerman (1946). The correlations of performance scores (integrated absolute error) with the reference test scores next were used in projecting performance measures onto the rotated axes defined by the reference battery. The procedure used was Mosier's extension method as described by Fruchter (1954). Appendix H presents the rotated factor loadings of all reference test scores and measures of performance.

Results

Interpretation of Factors in the Reference Battery

This section describes the interpretation of the 15 rotated factors extracted from the 50 reference tests. Test variables with the highest loadings are listed for each factor.

Factor I—Spatial Orientation. The first three tests listed below have served as reference tests of Spatial Orientation in many previous analyses (see, particularly, the review by Michael, Guilford, Fruchter, & Zimmerman, 1957; and studies by Roff, 1951, and by Fleishman, 1957b). This factor is defined as representing the ability to comprehend the arrangement of a visual stimulus pattern, primarily with respect to the subject's body as the frame of reference. Tests of this factor often ask: "What position am I in, if the situation looks like this?" (or vice versa).

No.	Variable	Loading
17	Stick and Rudder Orientation	.53
1	Aerial Orientation	.52
10	Instrument Comprehension	.47
47	Rate Control	.47
20	Visualization of Maneuvers	.46
14	Signal Interpretation	.45

Factor II—Control Precision. This factor involves the ability to make sensitive, highly controlled (but not overcontrolled) positioning adjustments, primarily where larger muscle groups are involved. These adjustments are made in response to visual stimuli. This factor has been called Psychomotor Coordination I (Fleishman & Hempel, 1956) and Fine Control Sensitivity (Fleishman, 1958b) in earlier studies, but the present label is more consistent with later interpretations.

No.	Variable	Loading
40	Rotary Pursuit	.60
25	Two-Plate Tapping	.41
49	Rudder Control	.40
28	Control Sensitivity	.38
37	Pursuit Confusion (Corrects)	.38
36	Pursuit Confusion (Errors)	.37
31	Bimanual Matching	.37

Factor III—Speed of Arm Movement. This factor is restricted to those tasks in the battery which have previously identified a Speed of Arm Movement Factor (Fleishman, 1954, 1957b, 1958b; Fleishman & Hempel, 1954a, 1955). This represents simply the speed with which a subject can make a discrete, gross arm movement.

No.	Variable	Loading
29	Ten Target Aiming (Errors)	.63
30	Ten Target Aiming (Corrects)	.50
43	Jump Visual Reaction Time	.36
44	Jump Auditory Reaction Time	.31

Factor IV—Manual Dexterity. This represents the ability to make skillful, controlled arm-hand manipulations of larger objects (Fleishman, 1953, 1954; Fleishman & Hempel, 1954b; Hempel & Fleishman, 1954).

No.	Variable	Loading
30	Ten Target Aiming (Corrects)	.42
24	Rate of Manipulation (Turning)	.40
23	Rate of Manipulation (Placing)	.38
29	Ten Target Aiming (Errors)	.35
25	Two-Plate Tapping	.35

Factor V—Reaction Time. This factor contains all the simple reaction time tests in the battery. It is defined simply as the speed with which the subject can react to a stimulus when it appears (Fleishman, 1954, 1958b; Fleishman & Hempel, 1955).

No.	Variable	Loading
43	Jump Visual Reaction Time	.52
42	Auditory Reaction Time	.51
41	Visual Reaction Time	.48
44	Jump Auditory Reaction Time	.48

Factor VI—Verbal Comprehension. This factor is defined as representing knowledge and understanding of the English language (French, 1951).

No.	Variable	Loading
18	Vocabulary	.67
50	Background for Current Affairs	.67

Factor VII—Response Orientation. This factor is defined as the ability to choose and perform the proper movement or direction of movement from several alternatives. The factor does not involve the interpretation of the spatial characteristics of the stimulus (Fleishman, 1957a, 1957b, 1958b; Fleishman & Hempel, 1956).

No.	Variable	Loading
34	Choice Reaction Time	.39
5	Discrimination Reaction Time (printed)	.38
7	Forced Landings	.36
14	Signal Interpretation	.30

Factor VIII—Arm-Hand Steadiness. This factor involves the ability to make precise, steady arm-hand movements of the type which minimize strength and speed. This ability is involved in tasks requiring maintenance of a steady arm position in space where the crucial feature is a minimum of tremor, as well as in tasks involving steadiness during limb movements (Fleishman, 1953, 1954, 1958a, 1958b; Hempel & Fleishman 1954).

No.	Variable	Loading
32	Track Tracing (Errors)	.42
45	Steadiness Aiming	.40
26	Precision Steadiness (Errors)	.34

Factor IX—Perceptual Speed. This factor involves the ability to make rapid comparisons of visual detail (Fleishman, 1956; French, 1951; Guilford & Lacey, 1947).

No.	Variable	Loading
16	Speed of Identification	.53
19	Visual Pursuit	.35
6	Following Directions	.31
16	Spatial Orientation	.30

Factor X—Visualization. This factor involves the ability to mentally manipulate visual images. Tests of the factor require that one move, turn, twist, or rotate (in imagination) one or more parts of a configuration in a certain specified sequence. The subject is required to recognize the new appearance, position, or location after the prescribed manipulations. (Fleishman, 1957b; Michael et al., 1957; Roff, 1951).

No.	Variable	Loading
8	Formation Visualization	.61
12	Pattern Comprehension	.58
17	Stick and Rudder Orientation	.57
20	Visualization of Maneuvers	.47

Factor XI—Integration. This factor has been defined as the ability to utilize and coordinate a number of disparate cues and activities quickly and accurately in order to produce an appropriate integrated single response (Fleishman & Hempel, 1956; Guilford & Lacey, 1947). While these printed tests involve such responses, the absence of the apparatus tests indicates that a redefinition of this factor may be necessary.

No.	Variable	Loading
3	Coordinate Movements	.40
2	Complex Movements	.30
4	Directional Control (printed)	.30

Factor XII—Pursuit Confusion Doublet. This factor is restricted to two scores on the Pursuit Confusion Test and is, hence, not interpretable in more general terms. The two scores were not expected to define the same factor (Fleishman, 1958b).

No.	Variable	Loading
37	Pursuit Confusion (Corrects)	.35
36	Pursuit Confusion (Errors)	.31

Factor XIII—Mechanical Experience. This factor primarily involves a knowledge of tools and an understanding of mechanical principles and the proper use of tools and mechanical devices (French, 1951; Guilford & Lacey, 1947).

No.	Variable	Loading
9	General Mechanics	.47
11	Mechanical Comprehension	.47
7	Forced Landings	.35

Factor XIV—Finger Dexterity. This factor involves the ability to make rapid, skillful, controlled manipulative movements of small objects where the fingers

are involved, primarily (Fleishman, 1953, 1954; Fleishman & Hempel, 1955; Hempel & Fleishman, 1954).

No.	Variable	Loading
21	O'Connor Finger Dexterity	.49
22	Purdue Pegboard	.43
23	Rate of Manipulation	.36

Factor XV—Multilimb Coordination. This factor is common to tasks in which the requirement is the simultaneous use of both hands, both feet, or hands and feet. These tests have defined this factor in previous studies (Fleishman, 1958b; Fleishman & Hempel, 1956).

No.	Variable	Loading
49	Rudder Control	.40
35	Complex Coordination Test	.38
33	Two-Hand Coordination	.30

Relation of Ability Factors to Stages of Practice in Tracking

This study was concerned with determining the kinds of basic psychomotor abilities underlying tracking proficiency and with the manner in which these abilities change as a function of practice. Figure 10 illustrates the extent to which the combined abilities account for variability in tracking performance at the various stages of learning. It will be noted that only in the terminal stages do these abilities account for as much as 25% of the variance. Figure 10 clearly indicates that the set of abilities defined by the reference battery in the present study does not account for any substantial portion of the variance in tracking performance. This is in contrast to previous studies with other psychomotor tasks. For example, in the case of the Complex Coordination Test up to 75% of the variance was accounted for by independent reference ability measures (Fleishman & Hempel, 1954a); over 50% was accounted for in the Discrimination Reaction Time Test (Fleishman & Hempel, 1955); roughly 60% in the two-hand and unidimensional matching and plane control tasks (Fleishman, 1957a).

Consideration next was given to the nature of the changes occurring during practice in those abilities which do show some relation to tracking performance. Based on integrated error score as a measure of performance, only Factors I (Spatial Orientation), VII (Response Orientation), XII (Pursuit Confusion), and XV (Multilimb Coordination) had factor loadings in excess of .20 at any stage of practice. Of these, only Spatial Orientation and Multilimb Coordination show systematic changes in importance during the course of practice. Figure 11 presents curves illustrating changes in the percentage of variance accounted for by these two abilities with increased practice. Multilimb Coordination shows an increase in importance during the course of learning while Spatial Orientation appears to be important only during the middle stages.

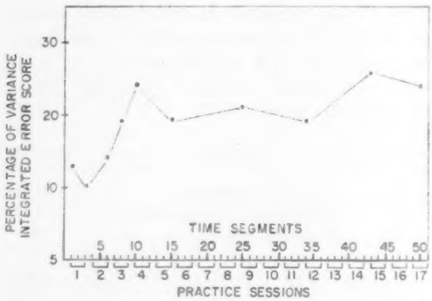

FIG. 10. Percentage of variance in tracking performance accounted for by all identified factors.

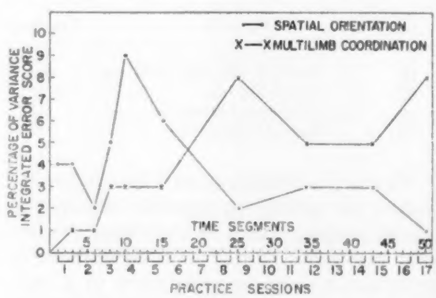

FIG. 11. Changes occurring in the importance of two ability factors with increased practice in tracking.

Consideration was given to the possibility that use of only 6 minutes of performance in the integrated error criterion measure might not have been a sufficient behavior sample and might have lowered the correlations obtained between performance and reference tests. Certainly use of an expanded measure of performance would increase the reliability of this measure even though it had previously been found to be sufficiently high (.89 at the terminal practice stage). In order to examine this possibility, several correlations between integrated error and three of the reference tests at the three stages of practice were recomputed, using a 21-minute performance measure rather than a 6-minute measure. Table 3 presents both sets of correlations. It does not appear from the changes in the correlation coefficients that any significant increase would have been obtained by using an expanded measure of performance.

Relationships among Component Performance Measures

It will be recalled that, at each of the practice stages, five measures of performance were obtained. These measures were:

1. Integrated absolute error
2. Azimuth (X) error
3. Elevation (Y) error
4. Sideslip (Z) error
5. Time-on-target (scope and sideslip simultaneously)

The integrated absolute error score is not an independent measure but is determined by the X, Y, and Z scores in accordance with the relationship described previously in Equation 1.

The above performance measures were obtained primarily with a view to answering the question: "For this type of task, how well do component performance measures predict terminal proficiency?" Table 4 presents the intercorrelations of all performance measures at an initial point in learning (first time segment) and at an intermediate point (twenty-fifth time segment).[3] The table also presents the correlations of all measures, at each of these stages, with terminal proficiency (fiftieth time segment) as measured by the integrated error score. It is apparent that initially all component measures are uncorrelated with terminal proficiency. In other words, neither initial component measures nor over-all measures allow the prediction of final performance in this task. At an intermediate point in the learning period, component measures do show some relation to the final score ($X = .28$, $Y = .36$, $Z = .34$) but none is sufficiently high to serve as a very useful predictor.

[3] It will be recalled that the full course of practice was broken into 51 time segments.

TABLE 3

CORRELATIONS BETWEEN SELECTED REFERENCE TESTS AND A MEASURE OF PERFORMANCE ILLUSTRATING THE EFFECT OF EXPANDING THE MEASURE OF PERFORMANCE

	Correlations: Previous[a]	Correlations: Expanded
Aerial Orientation—Session 5	.25	.25
Discrimination Reaction Time (Printed)—Session 5	.22	.25
Complex Coordinator—Session 5	.21	.24
Aerial Orientation—Session 9	.17	.14
Discrimination Reaction Time (Printed)—Session 9	.18	.17
Complex Coordinator—Session 9	.13	.14
Aerial Orientation—Session 17	.18	.09
Discrimination Reaction Time (Printed)—Session 17	.09	.12
Complex Coordinator—Session 17	.13	.14

[a] The performance measure (integrated absolute error) entering this correlation is a 6-trial "time segment." This time segment in each case forms a part of the 21-trial session which represents the expanded measure.

TABLE 4

INTERCORRELATIONS AMONG COMPONENT PERFORMANCE MEASURES AND A FINAL PROFICIENCY MEASURE

	Integrated Error	X Error	Y Error	Z Error	Time-on-Target	Final Integrated Error
TIME SEGMENT 1						
Integrated Error		.25	.15	.60	.35[a]	.04
X Error			.31	−.05	.46	.02
Y Error				−.16	.31	.08
Z Error					−.01	.12
Time-on-Target						−.02
TIME SEGMENT 25						
Integrated Error		.65	.72	.63	.92	.46
X Error			.68	.02	.64	.28
Y Error				.27	.68	.36
Z Error					.58	.34
Time-on-Target						.48

[a] The fact that time-on-target scores are not negatively correlated with the error scores is due to the process of converting raw scores to stanine form. At this time all score distributions were arranged so that high score was indicative of good performance.

Discussion

The rationale underlying this study is that there exists within the population under inquiry a finite number of abilities which are used in mastering a complex tracking task. These abilities are representative of the class of theoretical construct which is response inferred. They are response inferred in that, although the characteristics of the task remain unchanged, the performance of individuals exhibits major variation. The purpose of this study was to identify these abilities in terms of relations among the various performance measures (reference battery). Variability in performance at different stages of mastering the tracking task then could be accounted for in terms of the identified abilities. The validity of such ability identification is attested to by the factorial invariance found in previous studies using different reference tests (see Appendix A). The present study confirms this invariance using different subjects and a different combination of tests.

If tracking performance in fact can be accounted for in terms of a limited number of measurable human abilities, the results will have implication for such areas as human engineering design of equipment, personnel measurement and selection, and the identification of an efficient set of learning principles designed to improve training in tracking procedures.

Initially it might be well to indicate the rationale behind this study and the manner in which this study relates to the broad area of tracking research. Adams (1961) indicates that there exist two major kinds of tracking research. Engineering psychologists have used the theory of closed-loop servomechanisms as a model for investigating the man-machine tracking system. Adams points out the advantages and disadvantages of this orientation and notes that it results in research oriented toward *task variables*. Thus, system input-output relations are discussed in terms of time and frequency characteristics and are described through output errors resulting as a function of changes in system parameters. Such changes might be performed on the input signal, control system dynamics, or the control-error display relationships.

General experimental psychology, on the other hand, has used traditional behavior theory as its model and the tracking sys-

tem becomes a means of eliciting desired behavior classes. Such research is oriented toward *procedural variables* related to training, retention, stress, fatigue, motivation, etc. The major deficiency in this type of research is that apparently any task is considered appropriate if it elicits the desired response class. Little consideration is given to possible interactions between task and procedural variables.

The present investigation appears to fall somewhere between these two types of research. It is concerned with task variables to the extent of insuring a complex criterion task and defining the dimensions of complexity. These are a two-dimensional display system, control characteristics varying from zero-order to second-order, and requirement for dual-error nulling. Task variables were not used as independent variables, however. This study was not concerned with procedural variables as such, yet the results have implications for such areas as learning theory and training.

Identification of Perceptual-Motor Abilities

One major end product of this study is found in the identification of the ability factors measured by the tests within the reference battery. Forty-three printed and apparatus tests were administered to these subjects. (Fifty scores appeared due to use of subparts and correct and error scores as separate measures of performance.) Although the majority of these tests were chosen on the basis of their factor loadings in previous investigations, a number of new tests were introduced. Results of the factor analysis of these test intercorrelations serve further to define the basic components of human perceptual-motor abilities.

Changes in Ability Patterns with Practice

The general finding in investigations of this type (Fleishman, 1956, 1959) is that changes in the ability pattern underlying proficiency in the criterion task are quite systematic and progressive during the learning period. For the tracking task of this study, however, Figure 11 indicates that only Factor I (Spatial Orientation) and Factor XV (Multilimb Coordination) show a systematic relation to tracking performance during the course of practice. Apparently, early in practice the ability to interpret the visual display characteristics is of some importance. Later the ability to balance and to coordinate the activity of hands and feet in manipulating the control stick and rudder pedals plays some part in determining the proficiency of the subject. This is in keeping with the observation during the testing program that most subjects experienced extreme difficulty in effecting coordinated movements during the early part of the training program.

The Multilimb Coordination factor begins its major increase in importance at approximately the fifteenth time segment (Figure 11). This is roughly the same period when the sideslip (Z) error score, which reflects coordinated hand-foot activity, begins to show considerable improvement (Figure 7). There are thus two independent analyses in support of each other. An identified ability factor and a measure of component task activity both indicate the importance of coordination between limbs in determining proficiency at a given point in the practice schedule.

Predictability of Tracking Performance

One basic problem for consideration with any complex activity is whether terminal proficiency is better predicted by a set of external measures or by scores taken from initial practice periods in the activity itself. With the present tracking task there is no correlation between initial tracking performance and terminal performance. (The correlation between first-segment integrated error scores and fiftieth, or final, integrated error scores is .04). Based on the first time segment intercorrelations shown in Table 4, a multiple correlation analysis was performed. Results of this analysis indicate the extent to which terminal performance is predictable through use of the five performance measures taken during the initial practice session. The obtained multiple cor-

relation coefficient is .17, which is not statistically significant. In other words, scores obtained during initial practice periods in the activity itself do not predict terminal proficiency. It is interesting to note that even at the twenty-fifth time segment, when the subject has had approximately 4 hours of practice in the device, the correlation of integrated error score with terminal proficiency (terminal integrated error score) has risen only to .46.

In opposition to the above findings there are six of the reference tests which show correlations with final tracking performance of .26 or higher. The intercorrelations among these tests are presented in Table 5. The obtained multiple correlation using these tests as predictors of terminal proficiency is .43, which is significant at the .01 level.

These results indicate that early component and total scores taken from the task itself do not predict advanced proficiency levels until an intermediate stage of practice, and these are not high. If one must choose between intratask and independent measures, selected independent measures will give a better prediction of advanced tracking proficiency.

TABLE 5

RESULTS OF MULTIPLE CORRELATION ANALYSIS PREDICTING TERMINAL TRACKING PERFORMANCE FROM SIX EXTERNAL MEASURES

Variable	11	36	37	39	40	K
7[a]	.35	.25	.29	.37	.14	.26
11		.27	.19	.21	.21	.26
36			.48	.26	.31	.26
37				.31	.31	.26
39					.29	.30
40						.27

$R = .43$*

[a] These numbers correspond to the designation of the following variables during the machine data analyses:
Var. 7 = Forced Landings
Var. 11 = Mechanical Comp.
Var. 36 = Pursuit Conf. (Err.)
Var. 37 = Pursuit Conf. (Corr.)
Var. 39 = Discrimination Reaction Time (Appar.)
Var. 40 = Rotary Pursuit
Var. K = Segment 50 (Terminal) Integrated Error Score
* Significant at the .01 level (N = 203).

Human Performance in Tracking

The over-all operation of tracking a moving target can be examined in terms of component responses required of the human being. Adams (1961) has classified the component responses in tracking behavior into observing, predicting, and motor responses. These are defined below and are followed by a listing of those factors identified in this study which should be important to each response. In some instances certain factors appear to emphasize elements of more than one response class.

Observing Response. The sensing of display parameters including both input signal and error signal is by the observing response. The observing response appears to involve head and/or eye movements to direct the visual receptors to spatially separated stimuli, and the discrimination of stimulus change. The following identified factors would seem to be important for the observing response:

Factor I. Spatial Orientation
Factor IX. Perceptual Speed
Factor X. Visualization

Prediction Response. The prediction reponse involves predicting the regularities inherent in the input signal and the effect of control movements upon the error signal. This implies that the subject has learned the dynamics of the control system and the interactions between control movements and display changes. Poulton (1957) refers to such prediction as perceptual anticipation. Perceptual anticipation involves prediction of nature and size of muscular contractions required, prediction of duration of response movement, and prediction of future position of target at time of completion of response movement. For the criterion task of this study the following factors would appear to be important:

Factor VII. Response Orientation
Factor X. Visualization
Factor XI. Integration

The Rate Control factor, which was originally hypothesized, would fit in this category. However, this factor was not identified in the present study.

Motor Response. The motor responses are those activities involved in control system (stick and rudder) manipulations. It appears that the following abilities identified within this study would be of importance to such motor responses:

Factor II.	Control Precision
Factor III.	Speed of Arm Movement
Factor IV.	Manual Dexterity
Factor VII.	Response Orientation
Factor VIII.	Arm-Hand Steadiness
Factor XI.	Integration
Factor XII.	Pursuit Confusion
Factor XIV.	Finger Dexterity
Factor XV.	Multilimb Coordination

Identification of Abilities Underlying Tracking Proficiency

The preceding analysis would indicate that a successful tracking response is dependent upon a number of component responses. These component responses would, in turn, involve certain basic "abilities." The major objective of this study was to determine the extent to which a set of abilities as identified through use of the reference battery of tests accounts for variability in tracking performance at various stages in the practice schedule. The possibility existed that all of the factors listed in the preceding section would be important. As it turned out, this was not the case. As seen in Figure 10, at no stage of practice did these abilities, taken in their entirety, account for over 25% of the variance in tracking. As seen in Figure 11, only two of the identified abilities show any systematic relation to tracking performance. These are Spatial Orientation, listed under Observing Responses, and Multilimb Coordination, listed under Motor Responses. However, it should be noted that the contribution of the observing response factor decreases through practice while the motor response factor increases in importance.

The major question now becomes: "Why were these abilities not more effective in accounting for variability in tracking performance?" The need for some answer becomes more obvious when it is realized that in a previous study (Fleishman & Hempel, 1955) using a different criterion task (the Discrimination Reaction Time Test—DRT), over 60% of criterion task performance could be accounted for at some practice stages using the same kinds of abilities as in this instance. This 60% is as opposed to less than 25% within this study.

A possible answer may rest both with the nature of the tests within the reference battery and the nature of the criterion task. Considering the criterion task first, it has been noted that this tracking task was quite complex due to the dual display, the second-order control system characteristics, and the requirement for dual-error nulling. Another way of viewing this task might be that the subject was required to maintain a highly complicated and unstable system in a state of equilibrium. With tasks investigated previously such as the DRT, Rotary Pursuit, and the Complex Coordination Test, it appears reasonable that different abilities might be required for mastery. For example, with the DRT the subject observes a visual stimulus which differs on successive presentations only in terms of four possible configurations. The subject reacts by pushing one of four toggle switches as quickly as possible. For this task it appears logical that such abilities as Spatial Orientation, Reaction Time, and Rate of Arm Movement would be important.

The fact that a similar set of abilities did not account for a substantial amount of the variance in performance in the present instance may be explained if the task is examined in light of the three required reponse areas. The *observing response* in this task requires that the subject timeshare between two separate features of the over-all display. The *prediction response* requires that the subject develop the capability of predicting target position at some future time. When it is considered that the display actually is an error signal produced by improper control movements, it is apparent that prediction of target position would require a rather complex ability. This is particularly true since two dimensions of the control system involved second-

order controls. Thus the prediction of target position might involve such hypothesized abilities as the ability to perform double- and higher-order differentiations while compensating for built-in control system lag effects. Certainly proficiency in this task would require a different set of abilities than would be found with the DRT or the other tasks investigated previously.

The particular selection of tests for the reference battery used in this instance represents an attempt to continue with the same type of tests used so successfully in previous investigations employing different criterion measures. The lack of success of this comprehensive battery of tests in defining a set of abilities which would relate to tracking proficiency warrants a closer look at the tests selected. It appears that a set of abilities are important with this type of criterion task for which appropriate predictive tests have not been developed. Further work is required for the construction of such tests. Thus, if the criterion task is known to require time-sharing activities, the reference battery should contain tests designed to measure an hypothesized general time-sharing ability. There are no known reference tests which might be used to measure such an ability.

In short, while the reference tests used in this study reaffirmed a number of basic human perceptual-motor abilities, these abilities could not be related to any considerable extent to tracking performance. A complex tracking activity apparently requires abilities for which appropriate reference measures are not available at present. These abilities, further, do not fall within the area customarily called "Motor Abilities." Purely motor abilities do not determine individual differences in advanced tracking proficiency. The important abilities appear to fall within the areas of "Observing Responses" and, propably to a greater extent, "Prediction Responses." Further studies, obtaining basic measures within these areas, should be able to contribute additional information concerning the nature of a complex tracking activity.

Summary and Conclusions

This investigation was designed to provide information concerning the kinds of abilities which best predict performance in a complex tracking task. Consideration was given to the manner in which the underlying ability pattern exhibits change as a function of increasing proficiency in the task. The relation between early component performance measures and terminal proficiency in the tracking task also was examined.

A battery of reference tests containing both apparatus and printed tests of known factorial structure was administered to 203 subjects. Following this each subject spent a total of 17 sessions mastering the tracking task. Scores on the reference tests and various learning levels of the tracking task were analyzed through factor analysis techniques. Fifteen ability factors were identified and were related to the different stages of practice in tracking.

The following conclusions are drawn from the results of this study:

1. The kinds of perceptual-motor abilities which previously have been found to be related to performance on laboratory criterion tasks do not account for any substantial amount of the variance in performance with the present task. It is hypothesized that the complexity and particular dynamics of the tracking task used in this study require different kinds of abilities. Such abilities as Rate of Arm Movement apparently are not as important to the mastery of complex tracking activities as with laboratory psychomotor tasks. In tracking, the important determiners of proficiency may be found in those abilities used in the analysis of target motion and in the prediction of appropriate response movements, rather than in abilities related directly to control manipulation.

2. Initial component and total scores taken from the tracking task itself do not predict advanced proficiency levels. If one must choose between intratask and independent measures, the independent test measures give a better prediction of advanced tracking proficiency.

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APPENDIX A

Tests Which Measure Basic Psychomotor Abilities as Determined in Previous Studies

FACTOR	APPARATUS TEST	(LOADING, REFERENCE)[a]	PRINTED TEST	(LOADING, REFERENCE)[a]
1. Psychomotor Coor. I (Fine sensitivity) (1, 2, 3)[a]	1. Rotary Pursuit	(.48, 1)(.53, 2)(.47, 3)		
	2. Complex Coor. Test	(.48, 1)(.36, 2)(.50, 3)		
	3. Rudder Control	(.45, 2)		
	4. Pursuit Confusion	(.48, 3)		
2. Psychomotor Coor. II (Gross sensitivity; multilimb movements) (3, 4)	1. Rudder Control	(.56, 3)		
	2. Plane Control	(.50, 3)		
	3. Multi-dimen. Pursuit	(.38, 3)		
	4. Complex Coor.	(.37, 3)(.41, 4)		
	5. Rotary Pursuit	(.42, 4)(.08, 3)		
3. Speed of Arm Movement (1)	1. Reaction Time	(.54, 1)		
	2. Plane Control	(.33, 1)		
	3. Disc. Reac. Time	(.25, 1)		
	4. Rotary Pursuit	(.34, 1)		
	5. Rate of Movement	(.48, 1)		
4. Spatial Orientation (Stimulus interpretation) (3)	1. Controls Orientation	(.46, 3)	1. Direction Cont.	(.39, 3)
	2. Drift Correction	(.40, 3)	2. Instru. Comp.	(.46, 1)(.37, 4)
	3. Direction Control	(.38, 3)		
	4. Disc. Reac. Time	(.37, 3)		
5. Response Orientation (Response choice) (3)	1. Disc. Reac. Time	(.50, 3)	1. Signal Disc.	(.52, 3)
	2. Complex Mult. Reac.	(.41, 3)	2. Disc. Reac. Time	(.50, 3)
6. Perceptual Speed (1)			1. Visual Pursuit	(.50, 1)
			2. Speed of Ident.	(.47, 1)
			3. Spatial Orien.	(.45, 1)
			4. Disc. Pursuit	(.55, 3)
			5. Coordination	(.42, 3)
7. Visualization (1)	1. Direction Control	(.44, 3)	1. Pattern Control	(.60, 1)
	2. Controls Orien.	(.36, 3)	2. Mech. Principles	(.41, 1)
			3. Decoding	(.36, 1)

8. Mechanical Experience (1)			1. General Mechs.	(.62, 1)(.70, 4)
			2. Mech. Principles	(.49, 1)(.44, 4)
			3. Tool Functions	(.69, 4)
9. Numerical Facility (1)			1. Numer. Oper's II	(.66, 1)
			2. Dial & Table Reading	(.60, 1)
10. Psychomotor Speed (1, 2)			1. Log Book Accuracy	(.55, 1)(.59, 2)
			2. Speed of Marking	(.50, 1)
			3. Speed of Ident.	(.37, 1)
			4. Marking Accuracy	(.46, 2)
11. Wrist-Finger Speed (2)			1. Large Tapping	(.74, 2)
			2. Med. Tapping	(.74, 2)
			3. Pursuit Aiming—1	(.50, 2)
12. Finger (Fine dexterity) (2, 4, 5)	1. Purdue Peg Bd Both Hands	(.61, 2)		
	2. Purdue Peg Bd Left Hand	(.58, 2)		
	3. Purdue Peg Bd-Assm.	(.55, 2)(.35, 4)		
	4. Santa Anna Dext. Test	(.46, 4)		
13. Rate of Arm Movement (Probably same as Factor 2) (2)	1. 10-Target Aiming-Cor.	(.66, 2)		
	2. Two Plate Tapping	(.54, 2)		
	3. Rotary Aiming	(.46, 2)(.57, 4)		
	4. Rate of Movement	(.45, 4)		
14. Aiming			1. Pursuit Aiming—II	(.68, 2)
			2. Pursuit Aiming—I	(.63, 2)
			3. Aiming	(.63, 2)
			4. Irreg. Dotting Pursuit	(.82, 5)
			5. Speed of Sq. Marking	(.71, 5)
15. Arm-Hand Steadiness (2, 5)	1. Track Tracing	(.61, 2)		
	2. Steadiness-Aiming	(.60, 2)		
	3. Precision-Steadiness	(.50, 2)		
	4. Track Steadiness	(.56, 5)		
16. Reaction Time (2, 4)	1. Visual Reac. Time	(.73, 2)(.72, 4)		
	2. Auditory Reac. Time	(.68, 2)(.68, 4)		
	3. Jump Vis-Reac. Time	(.73, 4)		
	4. Jump Aud-Reac. Time	(.70, 4)		

APPENDIX A—Continued

FACTOR	APPARATUS TEST	(LOADING, REFERENCE)[a]	PRINTED TEST	(LOADING, REFERENCE)[a]
17. Manual Dexterity (2, 3, 5)	1. Santa Anna Finger Dext.	(.47, 2)(.38, 3)		
	2. 10-Target Aiming-Err.	(.43, 2)		
	3. Min. Rate of Manipulation (Turning)	(.38, 2)		
	4. Rotary Pursuit	(.35, 3)		
	5. DRT	(.34, 3)		
	6. Marble Board	(.51, 5)		
18. Postural Discrimination (2)	1. Post. Disc.—Angular	(.55, 2)		
	2. Post. Disc.—Vertical	(.48, 2)		
19. Integration (Coordination of hands and feet) (3)	1. Multi-dimen. Pursuit	(.36, 3)		
	2. Complex Coor.	(.36, 3)		
20. Rate Control (3)	1. Rate Control	(.58, 3)		
	2. Single-dimen. Pursuit meter	(.55, 3)		
	3. Compensatory Balance	(.39, 3)		
21. Verbal Comprehension (4)			1. Word Knowledge	(.78, 4)
			2. Background for Current Affairs	(.77, 4)
			3. Pattern Comp.	(.46, 4)

[a] References as indicated by numbers within parentheses:

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APPENDIX B

Description of Tests in Reference Battery

Printed Tests

1. *Aerial Orientation.* The subject is required to match the cockpit view of the horizon that corresponds to the airplane from which this view would be seen.

2. *Complex Movements.* Each problem presents a vertical line and above it a horizontal line. On each of these lines is a circle and a dot. Below the lines is a grid of 49 squares, one of which contains an "S." The examinee indicates in the grid from the letter S the direction required to "move" the dots on both lines simultaneously into their respective circles.

3. *Coordinate Movements.* Each problem presents a series of arrows which vary in curvature and represent different directions of movement. The thickness of each arrow represents distance of movement. To the left of these arrows are a dot and circle. The subject selects the one symbol (arrow) that will move the dot inside the circle.

4. *Directional Control.* Each problem presents nine boxes side-by-side with a target circle above the middle box. Also pictured is an arrow whose head indicates direction and whose length indicates distance of movement. The subject indicates from which box it must be launched to have its head reach the target.

5. *Printed Discrimination Reaction Time.* Each item simulates a setting of the apparatus test of the same name except responses are made by pencil in one of four slots on answer sheets. The slots are arranged in the same up-down, left-right pattern as are the toggle switches on the apparatus version.

6. *Following Directions.* Two panels of typical aircraft display instruments are presented to the subject. As the subject reads the text he underlines certain words depending upon relations among the instruments and upon directions appearing within the text. The test is designed to measure ability to work rapidly under the pressure of complex directions.

7. *Forced Landings.* Aircraft are depicted at certain altitudes above a number of boxes representing landing fields. Arrows are also shown on the display representing wind direction and magnitude and up or down draft currents. The subject must assess the situation and select the best landing field in terms of prescribed criteria.

8. *Formation Visualization.* The subject is presented with the top and side views of silhouettes of aircraft flying in formation. He then must select the correct alternative from among four front views of this same formation flight.

9. *General Mechanics.* Printed items require practical mechanical information dealing with the use of operation of familiar mechanical methods and devices.

10. *Instrument Comprehension.* For each item which presents views of cockpit instruments the subject must determine the proper position and orientation of an airplane.

11. *Mechanical Comprehension.* The subject is presented drawings of mechanical devices. He then must answer a series of questions concerning the operation of each device.

12. *Pattern Comprehension.* A series of drawings is presented which require visualization of relationships between components of solids and their unfolded, flat projections.

13. *Planning A Course.* The subject is presented a drawing of a maze-like arrangement of boxes. Starting at one end the subject must trace his way through the boxes, responding to coded instructions as to direction of travel which are presented within the various boxes.

14. *Signal Interpretation.* The subject is presented with a picture of a row of ships, each ship having an arrow beneath it. The subject traces from ship to ship in accordance with the pattern of flags being flown by each ship. Each problem continues until the subject returns to a ship used previously.

15. *Spatial Orientation.* The subject is presented with a large aerial photograph. This is followed by several small photographs, each presenting an expanded view of one section of the large photograph. The subject must connect each small photograph with the proper position within the large photograph.

16. *Speed of Identification.* Pictorial items are presented in which the silhouette of an object must be identified when it is rotated and imbedded in a group of similar silhouettes.

17. *Stick and Rudder Orientation.* A series of pictures is presented to the subject showing changing views through the windscreen of an aircraft. The subject is required to recognize the corresponding change in the position of the aircraft and to indicate the movements of stick and rudder required to produce such a change.

18. *Verbal Comprenhension (Vocabulary).* This is a typical vocabulary test requiring the matching of words and definitions.

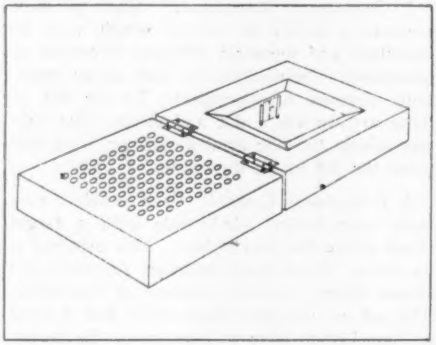
(50.) *Verbal Comprehension (Background for Current Affairs).* This is an informational test covering current, recent, and historical events.

19. *Visual Pursuit.* From a series of mazes or irregularly curved lines the task is to trace each line visually from its beginning to its proper termination point.

20. *Visualization of Maneuvers.* A picture of an aircraft is presented. This is followed by three descriptions of changes in the aircraft position. The subject then selects from among five alternatives that picture of the airplane which represents its final position following the described maneuvers.

Apparatus Tests

21. *O'Connor Finger Dexterity.* The subject is required to pick up three small pins at a time from a tray of pins with the preferred hand and place them three at a time in a small hole. He must fill a series of small holes in this manner as fast as possible. Score is the number of pins placed. One 5-minute trial.



22. *Purdue Pegboard (Summation Score).*

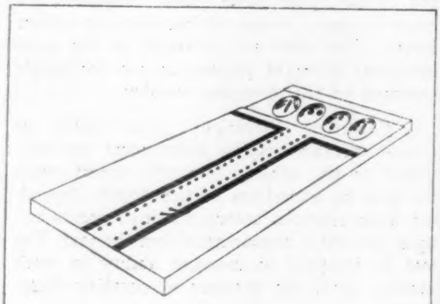
Right hand: The subject is required to place a number of small pegs individually in a series of small holes as rapidly as possible with the right hand. Score is the number of pegs placed. One 30-second trial.

Left hand: Same except with the left hand.

Both hands: The subject is required to pick up two pins at a time, one with each hand from different trays and place them simultaneously in two different holes. Score is the number of pegs placed. One 30-second trial.

Assembly: The subject is required to make as many completed peg-washer-collar-washer assemblies as possible in the time allowed. Score is the number of assembly components completed. One 30-second trial.

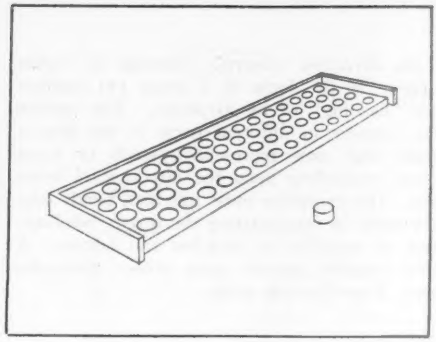
A summation of the four scores was used in the data analysis.



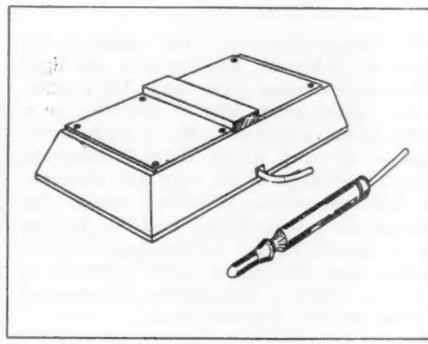
23. *Minnesota Rate of Manipulation.*

Placing: The subject is required to place 60 cylindrical blocks in the proper holes as rapidly as possible. The score is the number of blocks placed. Two 35-second trials.

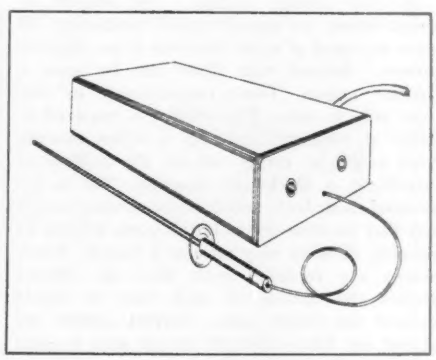
Turning: The subject is required to remove the blocks from the holes with one hand, turn them over with the other hand, and replace them in the same holes, moving from block to block as rapidly as possible. Score is the number of blocks turned. Two 40-second trials.



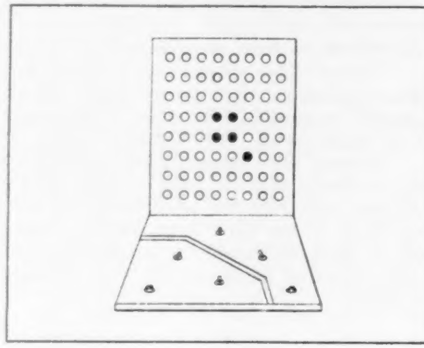
24. *Two-Plate Tapping.* The subject is required to strike two adjacent metal plates with a stylus as rapidly as possible. He strikes the plates successively; that is, first one and then the other, making as many taps as possible on the plates in the time allowed. The number of taps is recorded on counters. Three 30-second trials.



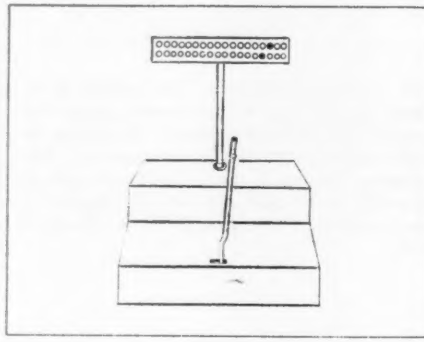
25. *Precision Steadiness.* The subject is seated before a long, rectangular box-like apparatus containing two openings. Each opening is the entrance to a straight passageway which the subject must negotiate with a long stylus. He moves the stylus forward at slightly below shoulder height and at arm's length. He must move the stylus slowly and steadily away from his body trying not to hit the sides of the cylindrical passage. As he reaches the end of the passage he strikes a contact point and withdraws the stylus, again trying to avoid hitting any part of the passageway. He then negotiates the second passageway. Two complete negotiations constitute a trial. Counters record the number of contacts and clocks record the number of times in contact. Six trials, no time limit.



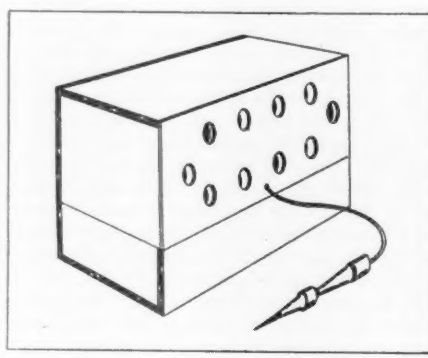
26. *Direction Control.* Patterns of lights appear in the form of a cross (to indicate the "heading" of an airplane). The pattern may appear in different parts of the display panel and may represent a small or large cross, depending upon the direction of heading. The examinee must use both hands concurrently in manipulating the proper combination of switches or switches and buttons. A new aircraft appears upon proper manipulation. Four 2-minute trials.



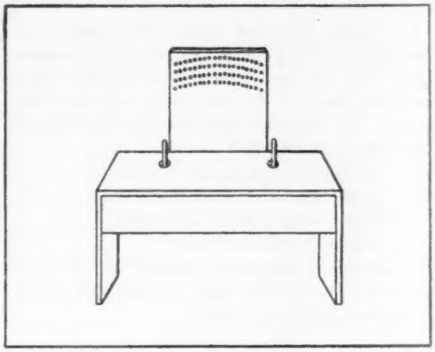
27. *Control Sensitivity.* The subject is required to match the position of a red light with a corresponding green light. The position of the lighted green light is controlled by a highly sensitive control stick. A slight movement of the stick to the right displaces the lighted green light to the right and, similarly, for left movements. When the subject has matched the two lights and held this position for .5 second, the red light moves to a new position and the subject again proceeds to match it. Score is the number of completed matches in four 1-minute trials.



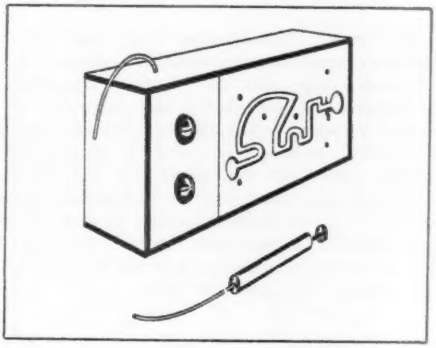
28. *Ten Target Aiming.* The subject is seated before an upright panel containing 10 holes arranged at equal intervals in an elliptoid pattern. Behind each hole can be seen a circular target. These targets vary in size from hole to hole. The subject is required to strike at these targets with a stylus moving from target to target around the pattern of targets in a clockwise direction. He is instructed that both speed and accuracy count and that he must try to hit as many targets as possible, striking only once at a target. Error counts are recorded each time the subject strikes the outside of each hole or inside around the target area. Correct counts are scored for hits within the target area in each hole. Six 30-second trials.



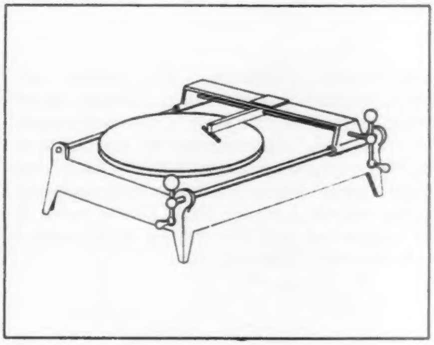
29. *Bimanual Matching.* A red row of stimulus lights has a parallel row of green lights above and below it. The subject must match lights simultaneously in each row of green lights with the red lights through movements of two handles. The movements of each hand sometimes correspond and sometimes are antagonistic to each other and bear a complex relationship to the position of the stimulus lights from setting to setting. Score is the number of simultaneous matchings made and held for .5 second during each of two 2-minute trials.



30. *Track Tracing.* The subject is required to negotiate an irregular slot pattern with a T-shaped stylus held at arm's length. Score is the number of errors (contacts with the back, top, and sides of slot) during four attempts. No time limit.



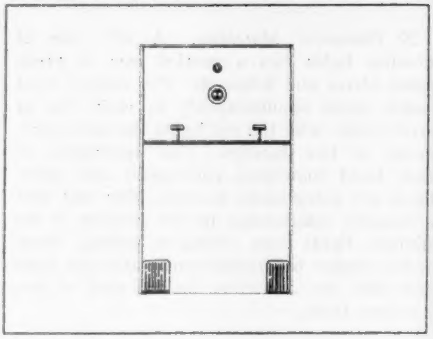
31. *Two-Hand Coordination.* The subject attempts to keep a target follower on a small target disc as the target moves irregularly and at varying rates. Movement of the target follower to the right and left is controlled by one lathe-type handle, movement to and from is controlled by the other. Consequently, simultaneous rotation of both handles moves the follower in any resultant direction. Score is the total time-on-target during four 1-minute trials.



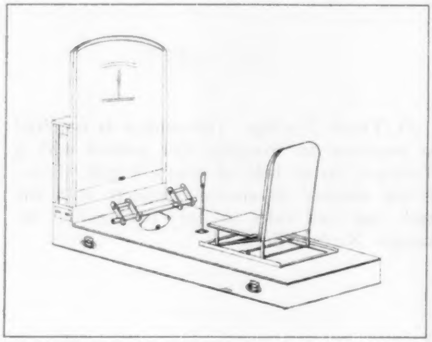
32. *Choice Reaction Time.* The subject is confronted with a panel containing a central light. He has two levers, one for the right hand and one for the left hand, and two foot pedals. He responds appropriately to any of four stimuli as follows:

red light—right lever forward
green light—left lever back
buzzer—right pedal depressed
bell—left pedal depressed

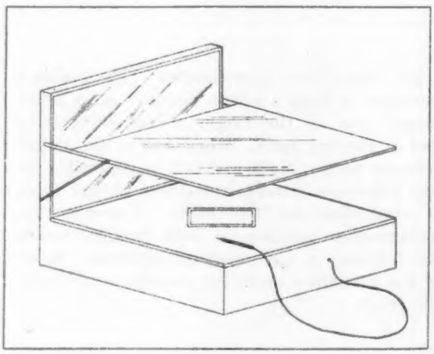
The subject is allowed 3 seconds in which to respond. The central light extinguishes when the correct response is made.



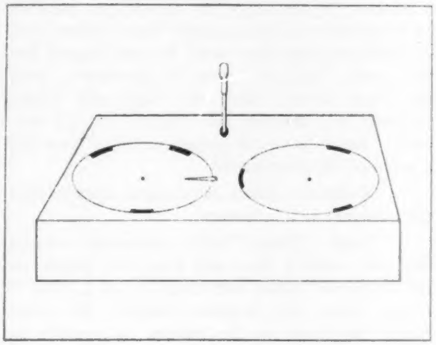
33. *Complex Coordination Test.* The subject is required to make motor adjustments of an airplane-type stick and rudder in response to successively presented visual patterns. A correct response (movement of stick and rudder controls to proper positions) is not accomplished until both the hands and feet have completed and maintained the appropriate adjustment. A new pattern appears as each correct response is completed. Score is the number of correct responses completed in a given test period. Four 2-minute trials.



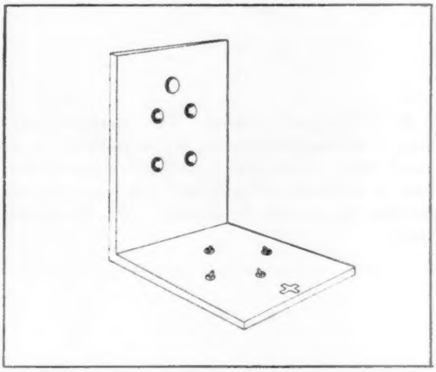
34. *Pursuit Confusion.* The subject attempts to keep a stylus on a variable speed target as it moves through a diamond-shaped slot. The task is complicated by the fact that the entire target area is visible only by mirror vision. Score (corrects) is the time-on-target during the six 1-minute trials. Error score is the amount of time the subject is in contact with the sides of the slot.



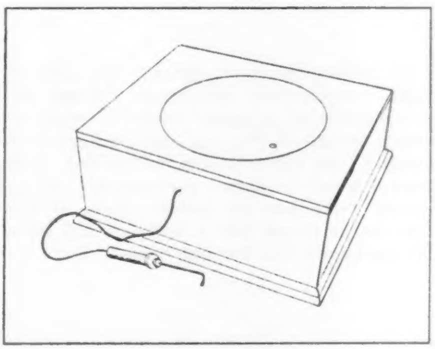
35. *Motor Judgment.* The subject is confronted by two adjacent discs rotating at a constant speed. Each disc has black and white sections on its perimeter. Between these discs is a pointer whose speed of rotation the subject can control. A forward movement of this stick slows the pointer and a backward movement speeds up the pointer. The subject cannot stop the rotation of the pointer completely and he can exert no control over the two rotating discs. The subject is required to manipulate the control stick so as to make as many revolutions of the pointer as possible without crossing the black areas on the rotating discs. To do this properly he must integrate his estimates of speed of each disc, the pointer, and his own control movements. Score is the ratio of the number of errors to the number of pointer revolutions during four 1-minute trials.



36. *Discrimination Reaction Time.* The subject manipulates one of four toggle switches as quickly as possible in response to a series of visual stimulus patterns differing from one another with respect to the spatial arrangement of their component parts, e.g., position of a lighted red lamp relative to a lighted green lamp. Score is the accumulated time of response for four series, each series containing 20 reactions for each stimulus pattern (subject must respond within 3 seconds).



37. *Rotary Pursuit.* The subject attempts to keep a prod stylus in contact with a small metallic target set in a rapidly revolving phonograph-type disc. Score is the total time-on-target during five 20-second trials.



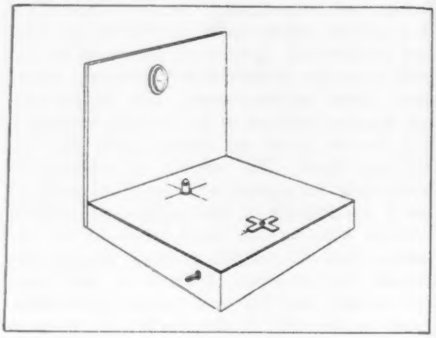
38. *Reaction Time Test.*

Visual: The subject keeps his finger on a button, depressing it as rapidly as possible in response to a single amber light before him. A click provides him with a ready signal before each light stimulus is presented, with the fore period (between click and light) varying in a random order from .5 to 1.5 seconds. Score is accumulated reaction time for a series of 20 reactions.

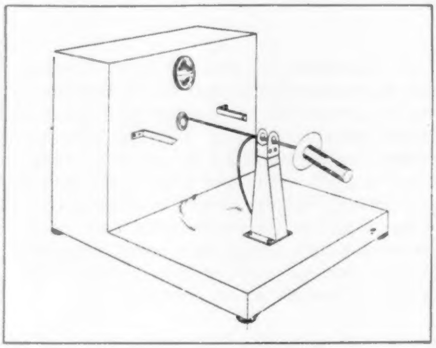
Auditory: Same procedure except that the response is to a buzzer.

Jump Visual: Same procedure except that the subject does not keep his finger on the response button but keeps it on a cross 6 inches from the response button. He must move his hand to the button as rapidly as possible as each light stimulus appears.

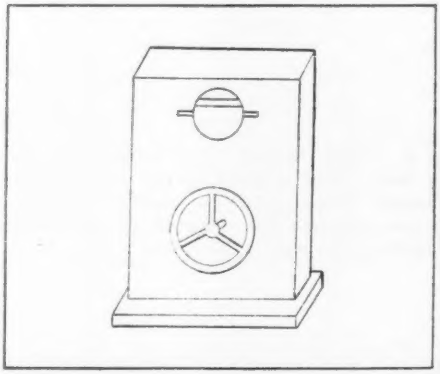
Jump Auditory: Same except response is to buzzer.



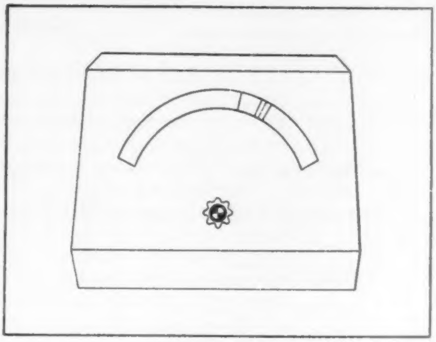
39. *Steadiness Aiming.* The subject must keep a delicately balanced stylus centered in a small hole. Any contact with the sides of the hole is recorded on a clock. The score is the number of seconds in contact. Six 40-second trials.



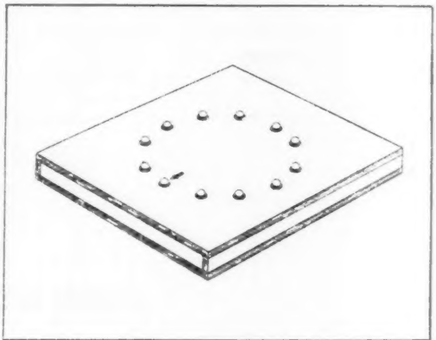
40. *Single Dimension Pursuit.* The subject makes compensatory adjustments (in and out movements) of a control wheel in order to keep a horizontal line in a null position as it deviates from center in irregular fashion. The control wheel is damped pneumatically, introducing a lag into the system. Score is the time the horizontal line is held in a null position during the four 1-minute trials.



41. *Rate Control.* A vertical target line moves back and forth across a curved scale with frequent changes in direction and rate of movement. The subject attempts to keep a thin pointer in coincidence with this line by adjustive rotary manipulations of a knob control. Score is the total time the pointer and target line are in coincidence during eight 1-minute trials.



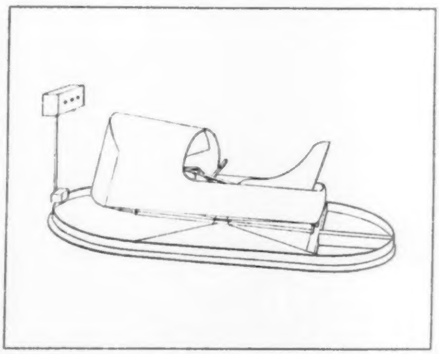
42. *Rotary Aiming.* The task is to strike at a series of buttons arranged in a circular pattern on a horizontal panel, going from one button to the next as rapidly as possible. Score is the number of strikes in four 30-second trials.



43. *Rudder Control.*

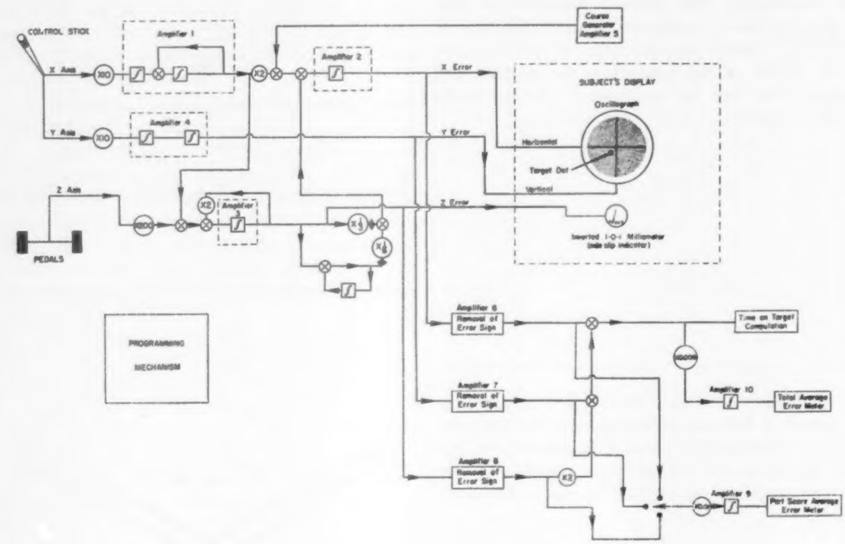
Center Target: The subject sits in a mock airplane cockpit which he attempts to keep aligned with one of three target lights as they come on in front of him. His own weight throws the seat off-balance unless he applies and maintains proper correction by means of foot pedals. In this condition only the center target is used. Score is the total time the cockpit is held aligned with the center light during three 30-second trials.

Triple Target: Same procedure as above except the subject must utilize appropriate pedal control to shift the cockpit from one light to another as these come on at random intervals. Score is the total time the cockpit is lined-up with the proper light during three 112-second trials.



APPENDIX C

Block Diagram of Tracking Device



SYSTEM BLOCK DIAGRAM

APPENDIX D

Intercorrelations, Means, and Standard Deviations among Reference Tests

VARIABLES	NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	Mean	*SDs*	No.
Aerial Orientation	1		21	40	32	24	30	26	45	45	54	43	38	34	30	22	19	55	28	38	54	02	10	-04	07	11	17	40	08	02	12	26	20	30	07	26	30	16	11	21	24	-03	07	-07	04	06	05	27	-02	31	16	5.03	1.93	1
Complex Movements	2			36	30	37	24	22	44	27	39	29	41	35	33	21	23	37	10	35	37	19	23	07	16	08	15	36	22	10	05	27	27	22	10	25	26	25	07	36	24	05	07	04	11	01	14	18	02	25	09	5.21	2.10	2
Coordinate Movements	3				40	32	38	40	43	29	40	37	40	35	41	27	25	46	17	39	36	05	14	-00	05	13	18	39	07	-00	06	23	19	27	06	20	28	17	07	29	14	03	12	09	06	-01	13	13	04	22	19	4.96	1.92	3
Directional Control	4					27	18	43	28	17	41	28	27	25	34	21	30	33	15	27	28	15	25	09	13	12	25	30	11	01	-04	29	15	27	06	25	26	21	06	27	27	04	06	03	04	-02	07	12	12	17	01	5.03	1.94	4
Discrimination Reaction Time (Printed)	5						20	28	25	21	39	17	27	25	21	25	36	19	10	28	27	12	21	14	18	22	13	36	25	-07	16	27	24	24	22	30	30	29	06	36	23	14	03	10	-28	-32	31	24	32	33	14	5.06	1.98	5
Following Directions	6							21	29	-11	01	16	16	14	23	25	36	32	26	35	34	-02	03	-12	-04	-06	21	20	09	06	-00	15	08	13	-02	13	11	10	-10	17	06	-04	-05	01	01	-07	05	11	-06	11	23	5.00	1.94	6
Forced Landings	7								31	29	37	35	30	29	34	16	32	35	18	32	38	13	22	15	10	17	18	29	23	-01	04	27	26	24	15	30	25	29	01	37	14	-03	14	02	14	12	03	16	-01	14	03	4.97	1.91	7
Formation Visualization	8									51	56	55	67	35	33	35	24	57	25	38	58	13	11	-06	01	00	20	41	11	11	-07	22	26	21	09	32	26	16	-03	31	17	-09	00	-04	12	12	11	21	-15	23	11	5.01	1.93	8
General Mechanics	9										49	63	53	28	22	26	15	45	24	33	40	14	13	-02	10	09	25	34	28	17	02	32	30	29	03	37	38	37	10	23	29	-13	05	-04	12	14	10	26	-06	37	11	4.97	1.97	9
Instrument Comprehension	10											45	50	39	44	37	35	56	28	37	48	04	16	-04	12	06	19	42	22	14	-01	31	25	28	20	36	35	27	09	36	23	-06	-02	-05	05	07	12	31	-03	26	13	5.05	1.96	10
Mechanical Comprehension	11												50	33	32	17	16	51	29	30	46	10	04	-03	00	-01	19	38	11	05	04	23	17	29	03	30	27	19	02	21	21	-11	04	-00	12	13	11	19	-11	26	20	5.24	2.02	11
Pattern Comprehension	12													35	28	22	19	52	23	39	49	21	23	04	11	06	25	44	09	11	05	28	27	22	05	19	32	28	00	35	22	-11	05	-01	06	08	04	13	-06	29	08	5.05	1.77	12
Planning A Course	13														48	25	25	38	09	41	31	-04	11	00	13	02	20	36	19	04	09	21	16	18	04	30	11	21	01	24	06	02	11	02	02	07	00	21	-04	21	23	4.99	2.00	13
Signal Interpretation	14															21	13	37	11	35	28	02	08	-09	02	09	13	25	10	03	-07	26	14	22	14	20	23	22	10	21	00	-03	04	-05	07	-01	06	22	-13	26	03	5.04	1.96	14
Spatial Orientation	15																32	32	-10	30	32	12	30	17	29	17	21	21	19	-08	13	20	19	16	13	31	18	18	04	18	08	-06	06	12	16	03	17	25	02	12	05	5.02	1.95	15
Speed of Identification	16																	-16	18	39	23	19	20	22	15	11	25	16	26	-04	-12	16	18	11	19	29	13	09	-01	21	17	-02	07	08	06	01	07	17	21	17	21	4.96	1.94	16
Stick and Rudder Orientation	17																		31	38	56	02	10	-12	06	-02	19	38	12	06	07	25	22	28	-02	31	33	24	01	30	25	-14	01	-02	07	12	16	25	-08	29	07	5.16	1.99	17
Vocabulary	18																			12	26	00	-08	-12	-06	-07	-02	11	04	-19	-20	-05	01	01	06	02	-10	05	15	-10	-03	01	-04	-01	-03	01	12	05	-01	06	51	4.96	1.89	18
Visual Pursuit	19																				44	29	23	05	13	07	20	33	17	05	13	34	27	33	03	38	32	28	12	27	14	-08	-00	06	07	-03	14	33	08	31	-01	4.84	1.83	19
Visualization of Manuevers	20																					-01	16	-03	03	07	13	41	16	-02	06	29	17	23	07	30	29	23	02	31	22	-20	-12	00	10	-03	14	25	-14	26	05	5.03	1.90	20
Finger Dexterity	21																						37	26	27	16	20	11	06	06	16	07	18	16	08	16	14	15	08	20	13	03	06	10	12	06	13	08	20	21	-08	5.06	1.93	21
Purdue Pegboard	22																							48	43	33	20	19	14	-00	18	26	32	15	10	20	23	21	13	23	23	-03	07	18	14	-04	08	21	19	15	-06	4.95	1.91	22
Rate of Manipulation (Placing)	23																								44	37	07	11	18	-04	20	03	09	03	13	08	06	09	14	16	21	09	06	15	14	01	08	04	23	10	-09	4.94	1.92	23
Rate of Manipulation (Turning)	24																									39	12	09	30	-06	17	21	12	22	06	22	09	26	07	20	23	00	11	08	11	02	15	12	25	24	-02	5.02	1.91	24
Two Plate Tapping	25																										15	10	28	-11	25	24	22	15	22	18	07	11	12	17	27	03	06	07	12	00	11	13	22	29	-09	4.99	2.00	25
Precision Steadiness (Errors)	26																											19	19	-01	18	29	39	14	10	26	09	16	13	22	26	11	12	15	12	15	08	25	09	37	-02	4.96	1.96	26
Direction Control	27																												20	11	01	23	22	35	13	35	25	22	12	32	25	-00	-06	-06	04	-01	16	15	00	26	-07	5.01	1.95	27
Control Sensitivity	28																													-10	29	26	16	20	25	48	16	29	09	30	21	09	12	20	21	10	16	25	08	32	-03	5.04	1.94	28
Ten Target Aiming (Errors)	29																														-55	06	09	-03	-12	-02	08	-00	10	-07	-01	-11	-08	-18	-07	-02	-09	-03	-01	00	-05	4.99	1.92	29
Ten Target Aiming (Correct)	30																															14	13	12	16	23	-01	05	-01	12	20	18	11	22	12	14	10	14	20	21	-05	5.06	1.89	30
Bimanual Matching	31																																30	37	16	38	36	30	13	17	34	-04	-02	01	11	07	07	31	06	43	-16	4.97	1.94	31
Track Tracing (Errors)	32																																	25	22	34	23	25	14	22	27	07	05	04	18	27	05	27	19	36	07	4.96	1.93	32
Two-Hand Coordination	33																																		13	45	31	36	19	28	31	-07	06	06	21	06	24	27	04	48	-10	5.02	1.97	33
Choice Reaction Time	34																																			25	-01	08	03	22	-01	20	07	11	17	20	-07	13	15	15	08	5.01	1.82	34
Complex Coordinator	35																																				26	33	13	31	25	08	10	13	16	17	21	41	12	44	-06	5.00	1.90	35
Pursuit Confusion (Errors)	36																																					48	20	26	31	-14	-04	-01	02	06	15	22	-04	30	08	4.97	1.98	36
Pursuit Confusion (Correct)	37																																						23	31	31	-14	04	07	08	09	24	22	-01	39	-10	5.02	1.96	37
Motor Judgment	38																																							08	26	-03	02	-02	-04	03	03	15	02	25	12	5.06	1.95	38
Discrimination Reaction Time	39																																								29	11	12	28	26	18	11	27	01	24	04	5.04	1.99	39
Rotary Pursuit	40																																									-06	-11	03	06	07	17	23	16	44	-12	4.93	1.99	40
Visual Reaction Time	41																																										38	24	26	19	-07	08	16	-04	-00	4.66	1.16	41
Auditory Reaction Time	42																																											23	32	07	01	23	21	-01	-14	5.03	1.43	42
Jump Visual Reaction Time	43																																												48	02	13	16	15	04	-05	4.33	1.72	43
Jump Auditory Reaction Time	44																																													19	19	29	17	20	01	5.53	1.71	44
Steadiness Aiming	45																																														03	14	-01	16	01	4.96	1.94	45
Single Dimension Pursuit	46																																															25	07	19	-00	5.00	1.96	46
Rate Control	47																																																13	36	-04	4.92	1.95	47
Rotary Aiming	48																																																	09	-03	5.11	1.81	48
Rudder Control	49																																																		-10	4.99	1.95	49
Current Affairs	50																																																			4.93	1.87	50

APPENDIX E

Correlations of Reference Measures with Tracking Performance Measures

TRACKING MEASURES

Reference Measures[a]	Integrated Error										Azimuth Error (X)										Elevation Error (Y)				
	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
1	16	18	23	22	29	25	17	24	24	18	08	-05	17	17	20	16	17	20	17	18	05	07	16	27	23
2	07	01	09	12	15	17	12	16	20	11	08	04	18	14	15	18	16	05	11	05	17	09	05	13	23
3	17	10	12	18	17	25	16	25	28	16	03	05	13	15	14	23	09	18	12	05	18	12	12	24	19
4	12	15	11	14	24	12	14	15	19	17	06	01	10	10	18	18	14	08	09	14	09	14	04	13	23
5	06	10	17	27	24	22	18	19	20	09	07	04	21	22	21	19	15	08	14	02	26	17	21	31	28
6	17	13	06	10	11	10	12	12	12	05	09	05	02	04	-02	10	08	06	05	08	10	04	00	07	06
7	07	10	12	14	26	20	20	17	22	26	10	07	08	08	15	13	19	14	07	09	08	09	07	10	14
8	10	13	14	19	21	18	16	20	20	11	00	02	16	13	14	16	15	04	02	07	-01	09	13	18	16
9	17	16	14	16	20	17	10	14	16	16	13	01	11	05	12	15	10	06	09	11	06	07	13	09	16
10	22	25	24	28	36	31	20	22	20	19	15	07	20	17	31	24	23	10	09	15	16	17	18	24	31
11	17	16	19	19	26	22	18	21	22	26	12	03	16	11	19	17	11	09	09	21	03	13	19	18	25
12	13	13	15	11	18	20	05	11	13	09	05	03	12	07	15	16	08	02	-03	-03	03	09	10	10	17
13	13	14	14	15	24	20	11	14	17	09	07	00	02	11	07	19	13	08	09	09	14	04	07	13	18
14	25	17	17	22	24	21	14	17	23	14	15	05	09	15	09	12	11	08	11	12	20	08	08	19	19
15	02	07	06	11	15	14	15	10	10	07	00	01	04	03	10	11	12	01	03	07	12	06	02	11	09
16	08	15	06	11	17	18	21	11	20	12	01	08	09	05	09	17	20	03	13	06	09	06	05	11	11
17	13	15	19	26	32	26	17	17	17	16	17	15	15	17	21	20	17	10	-02	11	09	16	16	24	27
18	12	15	12	16	13	13	11	09	12	08	06	07	07	11	01	05	02	05	03	03	03	11	11	06	03
19	16	15	14	14	21	18	18	13	24	15	11	-07	08	07	10	15	14	06	13	12	04	02	10	15	13
20	19	20	19	19	21	26	25	30	29	17	11	-02	12	13	15	14	20	24	16	17	10	15	12	18	16
21	-04	-01	04	-09	-02	07	04	05	12	08	-01	-01	07	-08	01	04	07	05	10	01	-01	-02	03	-04	02
22	-05	05	09	07	15	10	05	06	11	04	06	07	11	00	14	15	12	10	06	03	14	14	07	02	22
23	-02	02	04	-02	05	08	11	-01	09	09	06	03	10	-04	02	07	05	02	07	03	14	07	04	-06	10
24	03	09	02	06	10	08	-05	04	10	09	10	02	-02	-01	02	08	-04	-05	06	02	14	05	00	00	11
25	01	-05	07	-02	07	10	02	02	10	08	04	04	08	-02	03	12	01	01	11	07	08	08	05	01	11
26	01	05	00	07	06	03	08	04	06	04	-01	01	02	00	06	11	16	03	08	03	09	09	01	03	10
27	20	14	11	07	19	14	09	13	03	09	21	12	16	02	14	13	09	10	00	04	12	09	08	07	22
28	07	06	08	18	26	24	15	14	14	09	05	09	07	15	14	24	19	10	15	02	03	05	-01	10	20
29	-07	-10	-10	-13	-08	-04	05	-04	-06	-05	-02	-06	-02	-12	-03	-02	08	-09	-06	-04	-03	-01	-02	-09	-08
30	02	10	12	15	16	15	00	08	06	00	-01	00	14	16	12	17	-02	06	06	-05	00	06	05	17	18
31	15	17	11	15	19	11	09	04	11	03	01	-04	10	16	19	16	15	05	04	-03	10	10	11	18	21
32	-01	08	03	10	18	05	04	10	13	10	-03	-04	06	05	15	06	11	09	08	02	02	03	02	13	22
33	16	11	16	09	18	12	06	09	15	18	12	-01	14	07	08	10	03	-03	11	11	01	02	10	12	15
34	04	06	11	16	23	08	03	02	08	01	-02	10	20	22	20	13	06	-02	06	-06	11	10	12	16	25
35	08	14	11	18	26	21	13	19	19	12	08	03	11	16	16	24	20	04	20	09	08	12	08	18	21
36	18	17	28	18	25	24	25	28	31	26	12	06	20	11	22	15	22	19	16	15	10	12	23	17	25
37	-03	05	19	15	20	21	21	17	28	26	06	02	07	06	12	12	06	07	14	09	09	04	15	11	16
38	00	02	-01	01	05	07	05	13	05	16	-02	-08	04	-01	09	04	06	15	09	18	03	06	01	04	05
39	08	02	11	13	20	24	15	23	28	30	08	-01	07	15	15	20	13	08	17	22	11	07	09	18	22
40	09	19	09	12	23	28	24	22	24	27	10	09	12	03	21	26	17	15	17	17	13	19	14	13	27
41	-03	-01	07	10	02	02	06	04	04	-03	-03	02	08	17	-01	08	04	04	09	-03	15	03	02	10	06
42	01	00	01	01	-01	07	-02	-01	15	12	03	04	-05	06	04	08	02	-02	18	01	08	07	-02	-02	00
43	-03	04	17	14	03	08	03	13	17	17	02	03	05	13	02	06	-03	-01	14	15	10	02	10	04	03
44	00	-01	01	06	05	02	06	04	09	04	00	05	00	08	03	06	07	-01	09	03	17	03	-05	-01	03
45	-07	06	00	07	14	03	03	09	10	03	-02	06	09	08	11	00	00	08	07	-03	03	-01	-04	13	15
46	00	07	10	08	08	13	20	16	22	15	10	13	09	06	05	12	15	14	20	17	13	10	09	09	04
47	02	10	07	18	20	30	24	20	23	21	15	01	01	16	19	24	27	16	18	21	21	16	08	16	23
48	-02	06	-08	01	03	-02	-02	-07	00	-07	-01	05	01	01	04	00	01	-05	06	-07	17	10	-05	00	05
49	10	11	09	17	26	28	16	18	18	19	18	14	14	15	19	29	19	12	16	14	18	15	15	19	27
50	03	06	04	06	03	05	06	06	03	-04	-07	03	-06	00	-07	-07	-09	-01	00	-07	04	10	01	-05	-05

Reference Measures[a]	Elevation Error (Y)					Sideslip Error (Z)										Time-On-Target									
	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	20	16	10	20	12	18	11	-01	05	10	03	14	11	17	10	11	09	16	18	22	23	20	23	21	23
2	17	10	11	14	08	05	-08	-07	-05	-02	-04	05	13	12	05	06	12	12	10	15	21	17	16	18	12
3	22	19	16	21	02	10	03	06	-13	01	07	12	18	25	16	07	13	15	18	17	27	18	25	25	22
4	17	17	09	18	13	11	-02	-03	-03	00	-02	07	15	20	06	01	07	10	09	21	14	16	16	18	17
5	25	19	03	11	04	01	-05	-13	-07	-07	-01	14	16	20	15	13	15	23	34	26	23	22	22	20	16
6	14	03	06	12	02	20	12	07	04	04	-01	11	10	08	02	10	10	06	10	03	10	10	15	08	10
7	19	19	09	18	10	03	-05	-02	02	05	06	12	14	26	18	04	08	10	13	22	23	21	21	23	25
8	15	14	17	10	06	15	07	01	03	05	03	11	14	19	07	03	13	13	14	16	22	17	24	18	17
9	13	05	15	11	07	17	03	05	03	04	02	12	05	15	09	12	16	12	14	16	21	15	15	13	18
10	25	17	14	03	12	17	01	-03	05	03	13	12	20	21	13	17	19	24	27	36	32	22	26	21	23
11	20	09	17	10	14	13	04	-02	-04	11	04	19	10	19	18	13	14	16	16	21	25	20	22	19	28
12	16	11	15	08	05	10	-03	02	-01	-01	06	03	01	12	05	09	13	11	11	14	21	09	15	08	12
13	23	07	07	13	08	14	11	06	03	12	07	14	15	13	08	18	18	09	11	13	20	18	21	18	15
14	17	09	10	07	03	16	04	03	03	14	13	16	22	28	13	17	13	15	20	20	22	16	21	26	23
15	10	06	08	-05	01	02	00	-02	04	08	10	10	13	15	09	-01	07	02	11	14	18	14	12	10	13
16	23	20	07	17	13	13	05	-02	01	01	-03	10	10	19	14	-01	10	07	11	15	16	18	18	18	12
17	19	15	10	07	06	14	-02	-02	00	11	08	13	12	17	13	17	20	20	21	28	31	21	19	16	22
18	08	07	-03	02	06	16	07	01	05	10	14	18	17	09	09	09	07	05	05	04	09	03	14	10	09
19	19	09	05	16	06	15	07	10	08	10	04	18	13	22	11	07	13	15	13	14	18	17	18	22	20
20	18	23	14	17	17	12	05	04	10	06	10	14	17	24	13	07	13	12	14	20	28	23	30	24	27
21	09	01	08	10	-03	-01	-05	05	-06	01	02	-07	05	12	-02	-08	-06	05	-07	00	07	03	06	11	04
22	18	07	09	08	06	-03	-11	-03	03	05	-02	-07	05	06	-02	-01	12	12	07	15	12	04	07	09	07
23	13	03	-05	03	06	-01	-02	-06	-02	07	-01	11	05	13	04	-06	02	07	-02	02	06	11	-01	09	08
24	09	-05	10	07	10	03	-03	-03	-02	09	11	03	03	06	05	03	04	04	07	10	09	00	01	10	08
25	13	02	-01	07	08	01	-09	-05	-05	04	01	05	06	10	04	03	01	06	04	13	11	05	05	10	10
26	04	06	12	-03	00	08	-07	14	06	-03	-03	00	-03	05	-05	01	09	03	06	11	07	13	05	03	05
27	19	13	05	09	07	09	-02	-03	07	00	00	09	03	04	06	12	18	14	07	14	14	12	10	00	10
28	22	11	02	12	12	17	-01	-02	01	10	03	06	07	09	09	09	15	11	19	26	26	19	13	15	13
29	-03	05	01	07	06	-01	-07	00	00	-02	01	07	02	-05	-11	-04	03	-04	-18	-01	-11	03	-02	-08	-12
30	16	00	00	-07	-12	05	02	-02	-10	06	00	-04	04	10	08	11	02	14	18	17	18	02	07	06	05
31	19	14	11	05	00	10	-01	-05	-06	-06	-11	08	01	17	06	05	16	17	18	20	14	15	11	09	09
32	06	12	16	09	06	10	01	-05	-03	00	-06	02	08	11	03	-06	05	04	10	21	06	09	12	13	-08
33	12	03	02	08	06	14	03	00	01	03	04	10	04	17	14	10	13	19	13	16	16	10	09	14	22
34	18	07	02	02	-11	11	-06	-13	-12	-08	-02	09	05	04	08	09	14	18	21	27	13	06	01	06	01
35	20	16	06	09	06	14	04	05	-01	03	03	05	16	23	15	10	13	15	21	27	26	18	19	20	18
36	20	26	20	25	17	11	02	-03	03	06	10	18	12	27	22	12	19	26	21	21	26	23	25	32	28
37	12	10	14	17	15	03	-05	-01	01	07	21	24	16	29	28	08	12	18	14	18	28	23	20	28	29
38	-02	-05	04	10	10	03	-03	02	02	02	08	08	04	-04	14	-03	02	09	-05	04	04	09	14	08	15
39	24	14	11	15	12	15	-04	-10	-07	-08	05	13	23	32	25	12	11	14	14	20	29	19	27	28	33
40	22	24	16	27	18	08	02	05	02	09	13	20	12	23	26	09	14	09	11	24	31	28	23	20	29
41	07	07	-02	01	-09	-05	-06	-06	-07	-01	-05	-01	08	-01	-02	13	-02	12	11	09	05	10	05	06	-04
42	08	00	03	10	02	-03	-07	04	[illegible]	-06	-06	-06	09	10	05	15	01	-04	10	05	09	03	03	15	09
43	06	-02	02	-01	05	04	-04	02	05	17	07	05	17	21	18	02	05	08	08	04	07	04	16	16	18
44	10	02	03	-01	03	05	-07	06	-03	-02	-07	-03	08	08	06	05	03	07	08	10	10	04	05	05	07
45	-02	03	12	04	-04	05	-01	-04	-08	00	10	07	-01	09	01	05	02	05	10	14	08	05	11	09	07
46	06	12	10	07	17	-07	-07	-03	-03	05	09	04	07	14	11	04	13	08	10	07	15	20	17	19	19
47	27	16	20	07	16	02	-02	-01	06	04	11	15	13	19	11	20	12	11	20	25	32	29	24	21	23
48	02	00	05	03	-06	-01	-08	-05	-11	-03	-01	-01	-07	-03	-03	-11	-05	-06	02	02	-05	-05	-11	-04	12
49	23	12	10	09	07	13	-04	-02	-05	06	01	04	08	23	12	13	16	16	18	28	30	21	20	19	25
50	04	00	-02	-04	08	08	03	-01	03	07	12	14	10	07	05	08	07	05	03	04	10	07	07	06	07

[a] See Appendix D for identification of reference measures.

APPENDIX F

APPENDIX F

Intercorrelations, Means and Standard Deviations among Performance Measures

VARIABLE	No.	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	Mean	*SDs*	No.
Integrated Error Score 1	51		68	26	20	15	10	07	13	07	04	25	08	-01	-04	-04	00	05	03	04	00	15	05	02	02	02	05	08	09	04	-03	60	50	26	25	25	13	13	09	15	09	35	25	01	09	05	03	05	10	05	08	5.06	1.93	51
Integrated Error Score 2	52			43	37	29	19	18	23	13	11	24	29	12	08	11	05	10	12	11	09	21	36	22	18	18	10	15	18	08	05	36	37	11	19	32	22	19	12	16	15	37	45	18	23	20	12	13	20	11	17	5.04	1.90	52
Integrated Error Score 3	53				61	52	36	20	31	20	16	16	29	58	47	37	27	09	19	19	16	10	27	67	43	40	31	20	18	11	13	12	06	-05	03	24	17	18	17	18	18	33	42	70	52	47	34	17	29	21	18	4.99	1.98	53
Integrated Error Score 4	54					73	62	36	41	27	13	26	36	48	70	58	50	32	30	17	14	26	40	52	77	60	51	29	27	18	14	04	-04	-13	-05	15	16	19	25	25	20	32	40	53	83	66	58	34	40	26	19	5.01	1.92	54
Integrated Error Score 5	55						63	41	40	32	30	24	34	48	54	76	57	36	33	20	21	27	43	50	58	79	56	37	28	26	22	08	-08	-18	-08	11	14	21	24	29	28	29	34	55	69	86	62	40	42	34	32	5.00	1.94	55
Integrated Error Score 6	56							61	54	47	41	22	23	29	50	55	73	48	39	32	28	26	36	35	54	55	74	53	39	37	31	-03	-04	-14	-09	12	35	33	39	41	33	24	27	42	60	63	92	57	56	48	43	4.96	1.96	56
Integrated Error Score 7	57								65	60	46	-01	12	06	19	25	38	65	48	45	37	11	21	12	26	32	37	72	43	47	42	06	09	12	18	24	38	63	47	48	41	09	16	21	28	38	59	92	68	60	52	4.96	1.95	57
Integrated Error Score 8	58									71	57	03	04	10	26	23	30	38	67	59	53	08	14	12	34	32	33	53	68	57	46	17	14	15	14	25	42	47	66	57	48	11	15	19	30	35	48	63	92	70	62	5.02	1.99	58
Integrated Error Score 9	59										70	-02	-06	06	19	21	31	41	47	76	57	12	11	05	27	25	31	50	48	72	58	14	11	09	04	14	33	37	58	77	57	03	08	16	25	30	49	59	73	95	74	5.00	1.93	59
Integrated Error Score 10	60											02	-07	03	11	19	27	28	34	49	72	08	10	12	17	26	24	36	42	52	68	12	04	-04	00	13	30	34	51	65	74	-02	03	12	13	25	42	48	63	73	90	5.02	1.97	60
Horizontal Error Score 1	61												46	20	17	22	19	04	00	-05	04	31	30	26	18	29	22	00	00	-06	-04	-05	-09	-21	-13	-02	-01	-03	01	08	00	46	40	23	22	19	17	00	03	-02	06	4.99	1.99	61
Horizontal Error Score 2	62													37	31	28	30	09	06	-06	-09	25	42	34	25	37	21	13	-03	-06	-10	-15	-24	-26	-19	09	04	-01	00	02	-03	39	48	39	37	37	26	13	03	-03	05	5.03	1.89	62
Horizontal Error Score 3	63														60	56	41	17	16	08	00	21	34	68	57	54	39	19	03	03	08	-11	-30	-50	-39	-15	-14	-08	-04	04	01	25	35	71	55	53	33	07	08	07	03	5.00	1.99	63
Horizontal Error Score 4	64															68	61	28	27	12	09	21	33	56	80	65	54	24	12	10	10	-13	-25	-40	-51	-25	-15	-01	14	19	13	27	36	62	74	62	55	22	27	20	12	5.00	1.94	64
Horizontal Error Score 5	65																68	39	26	12	13	27	47	50	66	78	59	32	19	19	17	-13	-25	-38	-38	-32	-12	-05	08	19	16	24	35	55	65	81	58	27	24	21	17	4.96	2.00	65
Horizontal Error Score 6	66																	47	26	18	16	24	38	37	36	62	72	40	20	25	20	-10	-21	-29	-39	-21	-08	02	24	28	17	24	33	47	58	66	77	40	35	30	24	5.02	1.93	66
Horizontal Error Score 7	67																		53	39	26	14	23	15	36	39	48	68	36	40	35	04	-05	-05	-07	-10	-02	02	12	22	15	05	16	23	31	40	50	64	40	39	28	4.97	1.95	67
Horizontal Error Score 8	68																			56	32	01	12	15	31	27	30	48	59	55	39	04	02	02	-05	05	18	10	18	20	18	02	06	19	25	31	37	49	58	48	34	5.00	1.95	68
Horizontal Error Score 9	69																				56	-01	07	04	15	15	18	41	49	68	56	14	10	11	04	04	25	14	32	41	26	-02	04	13	17	21	32	44	55	71	50	5.00	1.93	69
Horizontal Error Score 10	70																					02	13	10	14	19	17	28	39	49	66	10	03	00	08	13	22	27	36	45	39	-04	07	07	08	20	28	39	53	58	70	5.05	1.95	70
Vertical Error Score 1	71																						48	18	19	32	30	11	00	00	02	-16	-25	-12	-08	-08	02	02	16	20	09	31	26	20	30	29	28	12	10	11	13	5.07	1.90	71
Vertical Error Score 2	72																							41	34	47	36	24	07	05	09	-23	-35	-27	-18	-07	03	01	11	15	01	32	49	40	39	47	37	21	16	11	17	4.96	1.97	72
Vertical Error Score 3	73																								55	55	35	22	11	00	08	-13	-24	-49	-31	-05	-07	05	01	08	09	31	43	72	55	51	35	12	13	07	09	4.97	1.95	73
Vertical Error Score 4	74																									64	55	28	24	18	13	-09	-20	-34	-43	-17	-10	03	20	24	18	26	35	53	77	64	54	28	35	26	18	5.01	1.93	74
Vertical Error Score 5	75																										59	34	24	17	20	-07	-23	-35	-36	-17	-05	07	18	23	23	29	37	57	64	80	57	35	33	26	26	5.07	1.88	75
Vertical Error Score 6	76																											44	27	27	18	-07	-13	-24	-29	-15	-03	07	23	23	20	24	26	44	56	60	72	37	36	30	26	5.01	1.97	76
Vertical Error Score 7	77																												50	48	41	04	01	-10	-01	00	16	27	25	35	28	05	17	30	31	37	52	68	54	50	39	5.05	1.97	77
Vertical Error Score 8	78																													45	43	12	12	03	04	08	29	22	26	27	27	03	03	13	23	22	35	42	62	46	42	4.98	1.95	78
Vertical Error Score 9	79																														61	14	13	07	04	02	19	19	30	41	30	-03	07	06	14	24	36	44	53	68	49	5.08	1.98	79
Vertical Error Score 10	80																															04	02	-06	00	-01	25	23	28	40	40	-06	09	08	10	19	30	41	51	58	63	5.09	1.99	80
Sideslip Error Score 1	81																																59	34	31	26	08	10	10	09	09	-01	00	-09	-11	-06	-08	02	11	12	10	5.01	1.95	81
Sideslip Error Score 2	82																																	42	39	32	21	19	10	07	14	-07	-08	-26	-20	-18	-13	02	12	10	08	4.96	1.97	82
Sideslip Error Score 3	83																																		54	35	29	21	13	02	01	-10	-18	-37	-29	-26	-18	07	10	04	01	5.03	1.92	83
Sideslip Error Score 4	84																																			59	41	33	14	03	01	-05	-13	-29	-27	-24	-16	09	12	03	05	5.04	1.92	84
Sideslip Error Score 5	85																																				48	43	25	16	15	06	03	-05	-08	-06	02	19	24	15	17	5.00	1.95	85
Sideslip Error Score 6	86																																					53	35	32	32	05	-01	-05	-01	03	26	30	41	33	[illegible]	4.99	1.96	86
Sideslip Error Score 7	87																																						51	42	41	12	08	08	05	10	27	58	51	37	43	4.91	1.94	87
Sideslip Error Score 8	88																																							66	53	10	10	07	17	22	36	47	74	59	57	5.01	1.94	88
Sideslip Error Score 9	89																																								68	11	12	11	23	26	42	50	65	80	72	5.00	1.93	89
Sideslip Error Score 10	90																																									02	02	10	21	21	32	43	55	61	76	5.01	1.95	90
Time-On-Target Score 1	91																																										55	38	37	31	25	13	11	06	01	3.72	1.74	91
Time-On-Target Score 2	92																																											44	42	35	27	19	17	08	07	4.60	2.03	92
Time-On-Target Score 3	93																																												63	59	49	24	19	17	13	4.72	2.19	93
Time-On-Target Score 4	94																																													74	62	31	30	26	18	4.84	2.01	94
Time-On-Target Score 5	95																																														67	40	36	33	27	4.83	2.04	95
Time-On-Target Score 6	96																																															60	52	49	45	5.02	1.97	96
Time-On-Target Score 7	97																																																70	62	56	4.99	1.93	97
Time-On-Target Score 8	98																																																	74	70	4.98	1.92	98
Time-On-Target Score 9	99																																																		78	5.00	1.94	99
Time-On-Target Score 10	100																																																			4.98	1.96	100

APPENDIX G

Unrotated Factor Loadings

VARIABLE	No.	FACTOR I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	h^2
Aerial Orientation	1	60	-25	04	-06	-15	-01	-04	08	10	21	-17	-05	09	05	05	55
Complex Movements	2	55	-04	03	13	14	05	02	-02	06	-09	11	09	22	-08	-03	45
Coordinate Movements	3	57	-18	18	13	05	13	02	-05	16	16	05	05	01	01	05	49
Directional Control	4	50	-03	03	21	09	13	11	-04	23	16	02	-17	-14	06	06	47
Discrimination Reaction Time	5	50	11	07	24	-13	10	17	03	13	-16	15	-01	17	-05	00	47
Following Directions	6	40	-31	21	11	-05	07	06	-06	-19	10	12	02	-04	-03	15	41
Forced Landings	7	54	-03	12	12	09	09	07	01	15	-08	-02	-09	-36	07	00	51
Formation Visualization	8	66	-37	09	-03	15	-08	-21	13	-09	-11	02	-08	08	03	-09	71
General Mechanics	9	64	-19	-13	-19	00	-28	-10	05	-10	-08	-06	04	-13	-15	13	66
Instrument Comprehension	10	70	-25	05	06	-01	00	09	03	-01	-10	-12	-08	07	09	01	61
Mechanical Comprehension	11	60	-33	06	-15	-01	-18	-18	05	04	00	-02	-03	-17	-15	07	62
Pattern Comprehension	12	65	-25	-04	05	18	-12	-27	18	06	-06	10	08	00	-10	-06	67
Planning A Course	13	51	-17	19	07	04	17	15	04	-11	03	-12	27	03	-16	05	52
Signal Interpretation	14	49	-22	08	01	09	27	22	-07	02	07	-14	16	-11	04	-12	51
Spatial Orientation	15	45	09	10	15	00	09	-13	-06	-28	-04	-14	05	06	15	-03	40
Speed of Identification	16	41	13	23	36	-09	-07	18	01	-24	-02	17	-17	-11	-03	04	54
Stick and Rudder Orientation	17	64	-35	-02	-19	00	07	-22	-01	12	08	-13	08	09	07	-02	68
Vocabulary	18	22	-35	31	07	-34	-38	01	-19	14	07	-06	-10	-06	-04	-13	63
Visual Pursuit	19	61	-05	-01	10	02	12	02	-10	-22	16	12	02	-01	-06	-15	52
Visualization of Maneuvers	20	63	-29	01	01	-12	12	-22	00	-07	-07	-02	-14	05	16	03	62
Finger Dexterity	21	25	30	-09	19	18	-19	-16	-01	-03	10	18	-01	-08	-12	-27	42
Purdue Pegboard	22	37	40	-11	35	15	-06	-18	-03	-02	07	-06	10	-02	16	-03	52
Rate of Manipulation (placing)	23	14	51	-05	37	05	-12	-18	01	07	-07	-15	01	-04	-02	04	50
Rate of Manipulation (turning)	24	28	45	-11	26	-04	-06	-13	-08	-04	-03	-27	11	01	-12	00	49
Two Plate Tapping	25	25	45	-08	16	-12	-01	-03	12	08	02	-24	-01	-01	06	06	42
Precision Steadiness (errors)	26	40	20	04	-08	08	-11	08	20	-13	23	15	05	-07	03	14	39
Direction Control	27	57	-10	-09	07	05	09	00	08	13	-07	-03	-15	18	-15	-04	47
Control Sensitivity	28	39	35	08	-11	-18	02	11	-02	-12	-31	-11	-04	-04	-15	14	51
Ten Target Aiming (errors)	29	-03	25	34	-09	-49	25	-25	04	13	03	09	06	-13	05	-12	61
Ten Target Aiming (correct)	30	18	46	20	-11	-35	17	-23	28	-03	09	12	16	02	-05	-01	63
Bimanual Matching	31	51	15	-23	-10	-01	11	15	08	-07	08	-02	-03	-06	08	06	42
Track Tracing (errors)	32	46	20	-06	-08	11	-22	15	21	-05	07	09	08	03	18	-07	44
Two-Hand Coordination	33	51	15	-20	-21	-07	09	08	-16	08	07	01	-13	-01	-08	-13	47
Choice Reaction Time	34	21	24	23	-02	-05	-05	21	19	04	-21	-07	-09	00	14	-16	34
Complex Coordinator	35	59	24	-01	-19	-09	04	16	02	-17	-10	-05	-12	02	-09	-08	54
Pursuit Confusion (errors)	36	50	-02	-33	-02	01	02	04	-16	11	-09	16	15	-04	13	04	47
Pursuit Confusion (correct)	37	48	15	-29	-10	-06	03	07	-23	08	-18	10	17	-15	-05	-04	51
Motor Judgment	38	17	12	-22	-02	-12	-21	20	-14	15	10	-04	13	05	05	-03	27
Discrimination Reaction Time	39	52	18	10	-03	14	09	-03	-03	15	-24	14	03	04	07	05	45
Rotary Pursuit	40	43	24	-34	-04	-16	-09	-05	06	16	09	11	-09	09	02	24	51
Visual Reaction Time	41	-03	28	44	-14	17	-02	17	12	21	04	01	00	15	-09	01	45
Auditory Reaction Time	42	09	26	35	-17	29	03	03	-08	11	12	-13	05	-07	-18	01	40
Jump Visual Reaction Time	43	11	38	36	-14	12	03	-18	-28	00	-04	16	00	04	07	15	49
Jump Auditory Reaction Time	44	22	33	31	-32	24	-12	-15	-23	-03	-01	-05	-08	-01	13	05	54
Steadiness Aiming	45	14	12	10	-31	07	-20	06	22	05	-12	02	08	-08	11	-11	29
Single Dimension Pursuit	46	24	14	-04	-09	-14	-01	-13	-32	-04	00	05	-08	12	-05	-08	26
Rate Control	47	45	21	05	-27	00	-02	09	-15	-17	12	-08	-01	09	12	-04	42
Rotary Aiming	48	07	41	11	14	03	-13	06	00	02	21	-01	-13	09	-07	00	30
Rudder Control	49	55	23	-25	-25	-15	-09	11	03	-03	13	02	01	02	-06	-03	55
Current Affairs	50	09	-29	33	21	-25	-41	15	-12	02	-05	04	23	08	09	06	59

Note.—Decimal points have been omitted.

APPENDIX H

Rotated Factor Loadings

VARIABLE	No.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	h^2
		FACTOR															
Aerial Orientation	1	52	05	−01	08	−12	25	05	05	−02	20	26	−11	13	−07	17	53
Complex Movements	2	16	10	−15	04	19	13	20	01	10	34	30	13	04	04	19	42
Coordinate Movements	3	36	00	−05	11	15	24	19	−01	03	18	40	06	14	04	−03	47
Directional Control	4	34	13	−16	05	08	13	27	−07	01	04	30	−11	17	20	−12	45
Discrimination Reaction Time	5	07	30	−10	15	14	20	38	−06	14	13	25	04	02	−04	17	45
Following Directions	6	27	−10	−01	02	05	23	06	04	31	09	27	06	20	−16	−08	40
Forced Landings	7	29	12	−03	09	07	11	36	08	04	13	10	−03	35	20	−15	48
Formation Visualization	8	33	−11	−03	−03	−05	18	15	15	20	61	19	−06	18	04	12	70
General Mechanics	9	29	18	−04	−12	−04	19	−11	19	11	38	07	02	47	01	21	64
Instrument Comprehension	10	47	09	−16	02	−01	24	28	08	15	33	14	00	16	−05	13	59
Mechanical Comprehension	11	32	−03	07	−06	−05	21	−02	11	04	38	17	−06	47	03	12	58
Pattern Comprehension	12	16	01	−08	05	−05	16	06	17	07	58	32	00	27	16	14	65
Planning A Course	13	31	−10	−13	25	17	11	14	13	10	12	23	22	24	−16	−16	50
Signal Interpretation	14	45	−10	−12	10	06	01	30	05	−01	03	18	25	19	01	05	47
Spatial Orientation	15	34	10	02	27	10	01	06	05	30	24	−01	10	−03	06	04	38
Speed of Identification	16	09	17	−05	15	16	20	23	08	53	06	13	−10	14	10	00	53
Stick and Rudder Orientation	17	53	−04	05	02	−11	16	03	01	−12	57	25	07	17	−03	14	77
Vocabulary	18	−18	−18	13	−04	−12	67	05	−03	08	15	−02	−06	11	13	02	60
Visual Pursuit	19	35	03	00	07	04	−01	13	−02	35	14	33	14	16	16	18	50
Visualization of Maneuvers	20	46	08	07	05	−16	16	16	−08	21	47	16	−04	13	−07	01	62
Finger Dexterity	21	−08	07	−03	04	05	−01	−02	05	18	13	17	00	05	49	16	36
Purdue Pegboard	22	14	33	−13	33	15	−04	−02	07	14	16	09	06	−10	43	−02	53
Rate of Manipulation (placing)	23	−10	35	−13	38	20	00	−05	−02	03	06	−10	−09	−06	36	00	49
Rate of Manipulation (turning)	24	08	33	−13	40	18	−02	−10	−07	05	06	−10	06	04	27	19	47
Two Plate Tapping	25	14	41	−05	35	08	−04	04	04	−04	−05	−07	−13	−02	17	12	38
Precision Steadiness (errors)	26	20	22	06	−01	13	−06	−05	34	16	−01	28	−08	14	08	08	37
Direction Control	27	24	11	−19	03	04	08	23	−10	02	34	25	−12	14	00	26	45
Control Sensitivity	28	13	38	10	13	29	00	17	01	14	06	−19	01	26	−11	24	50
Ten Target Aiming (errors)	29	−06	07	63	35	−05	04	15	−13	−09	14	03	−03	−01	−05	02	59
Ten Target Aiming (correct)	30	−06	26	50	42	07	−13	01	10	00	−04	18	−07	01	−07	18	60
Bimanual Matching	31	33	37	−17	08	−04	−13	14	05	14	04	20	01	14	09	10	42
Track Tracing (errors)	32	21	29	−03	−06	04	−01	10	42	09	10	16	00	−02	18	20	43
Two-Hand Coordination	33	37	25	07	−13	04	−07	15	−16	−02	06	14	04	18	17	30	45
Choice Reaction Time	34	06	15	07	09	12	06	39	25	02	−02	−15	−11	−07	02	15	33
Complex Coordinator	35	34	28	09	00	17	−08	23	07	21	10	00	−03	20	02	38	53
Pursuit Confusion (errors)	36	23	37	−08	−15	−08	02	11	−04	00	24	21	31	14	11	03	46
Pursuit Confusion (correct)	37	17	38	−01	−11	05	01	13	−08	−01	15	05	35	28	18	16	49
Motor Judgment	38	14	28	−11	−11	−06	15	−04	02	−11	−14	04	17	−04	13	20	27
Discrimination Reaction Time	39	14	28	07	01	29	04	29	07	−01	34	15	08	08	09	01	43
Rotary Pursuit	40	17	60	−02	−06	−04	01	00	−05	−04	12	27	−14	08	04	12	53
Visual Reaction Time	41	−08	−07	13	03	48	05	15	21	−22	−16	07	−16	−13	−02	09	46
Auditory Reaction Time	42	12	−14	11	07	51	−04	−01	12	−20	−09	01	−05	10	16	05	41
Jump Visual Reaction Time	43	03	13	36	01	52	01	−04	−02	05	07	00	04	−11	10	−14	43
Jump Auditory Reaction Time	44	26	07	31	−12	48	−01	−06	13	−02	14	−16	−04	−06	20	−01	52
Steadiness Aiming	45	02	07	18	−12	04	−02	11	40	−13	08	−10	−03	05	05	14	28
Single Dimension Pursuit	46	15	15	19	−06	10	07	−05	−26	12	11	−01	08	−03	10	20	25
Rate Control	47	47	19	15	−08	21	01	01	11	15	03	01	07	−02	07	25	44
Rotary Aiming	48	−03	−01	02	12	26	09	−09	03	08	−21	11	−21	−14	17	07	26
Rudder Control	49	34	40	08	−08	00	−08	00	09	03	03	18	03	19	08	40	54
Current Affairs	50	−02	07	−02	01	−03	67	−04	19	15	−05	−01	19	−08	−12	01	58
Integrated Error Score 1	51	20	−05	−10	04	02	13	02	−08	00	01	11	−02	16	−12	06	13
Integrated Error Score 2	52	20	01	−06	03	00	12	−01	−03	10	−02	−08	−05	08	−06	12	10
Integrated Error Score 3	53	14	02	07	09	05	14	08	−11	−06	14	06	16	07	00	09	14
Integrated Error Score 4	54	23	04	02	00	12	16	13	09	01	06	04	09	−01	−17	17	19
Integrated Error Score 5	55	30	11	−02	08	01	13	22	12	−01	06	01	04	10	−06	18	24
Integrated Error Score 6	56	25	12	04	10	10	15	07	−05	00	10	07	12	09	−08	16	19
Integrated Error Score 7	57	14	08	11	−07	04	18	13	−08	13	03	07	08	02	00	28	21
Integrated Error Score 8	58	16	10	09	−07	07	14	12	−03	00	13	12	14	00	−04	22	19
Integrated Error Score 9	59	18	03	08	−04	18	18	11	−03	03	09	10	21	10	13	22	26
Integrated Error Score 10	60	11	06	05	−11	12	18	03	−10	−09	06	03	14	17	13	29	24
Horizontal Error Score 1	61	19	05	−03	03	06	16	−05	−16	−05	04	01	05	09	−01	02	11
Horizontal Error Score 2	62	05	06	−02	−01	09	10	05	−04	−02	04	−05	−05	01	−01	−03	04
Horizontal Error Score 3	63	09	13	02	02	−04	13	21	02	−06	13	10	−06	−09	05	−01	13
Horizontal Error Score 4	64	18	05	05	−07	16	09	23	09	00	04	03	03	−10	−18	04	18
Horizontal Error Score 5	65	14	12	−01	−02	−05	05	21	11	−04	11	07	−04	−06	−01	21	16

APPENDIX H—Continued

VARIABLE		No.	FACTOR I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	h^2
Horizontal Error Score	6	66	21	14	02	10	16	06	04	00	04	04	13	−02	09	−11	13	16
Horizontal Error Score	7	67	21	03	05	−05	03	01	14	03	16	00	07	−01	−03	−01	19	14
Horizontal Error Score	8	68	14	03	00	−05	−02	10	00	03	04	01	10	07	−07	−03	20	10
Horizontal Error Score	9	69	13	12	04	−05	19	06	−06	19	04	−10	08	10	03	02	16	16
Horizontal Error Score	10	70	19	−01	03	−07	10	09	−11	−15	04	02	00	10	03	−01	26	17
Vertical Error Score	1	71	20	06	−10	08	29	10	02	−03	−03	−02	08	10	−15	−03	14	21
Vertical Error Score	2	72	17	07	−02	06	03	16	02	00	−04	01	05	−08	−08	00	15	10
Vertical Error Score	3	73	07	09	05	00	−04	16	09	−05	−06	09	09	09	00	01	08	06
Vertical Error Score	4	74	13	08	03	−03	06	06	24	08	−03	05	17	05	−09	−15	05	16
Vertical Error Score	5	75	18	18	−08	10	04	05	19	16	−10	10	02	−02	−03	−03	15	19
Vertical Error Score	6	76	19	09	−02	14	17	10	13	−01	07	06	10	−01	08	−04	13	17
Vertical Error Score	7	77	08	03	05	−07	−01	09	24	−01	05	06	12	−07	−05	−01	23	17
Vertical Error Score	8	78	10	00	04	−03	01	00	−01	12	02	07	13	08	02	04	11	07
Vertical Error Score	9	79	01	04	02	−02	04	13	11	−10	−04	−02	18	04	16	06	16	13
Vertical Error Score	10	80	10	05	−02	−03	05	15	−06	−19	00	03	−08	08	10	03	26	16
Sideslip Error Score	1	81	12	−01	04	00	−01	13	09	11	09	−02	02	02	18	−07	09	11
Sideslip Error Score	2	82	08	−08	−04	02	−08	16	−05	03	14	−03	01	02	08	−15	−01	09
Sideslip Error Score	3	83	03	−10	06	−03	01	−06	−19	01	10	−07	09	05	15	01	−01	10
Sideslip Error Score	4	84	05	−08	−02	−03	−05	01	−10	−03	13	01	−07	06	00	−05	11	06
Sideslip Error Score	5	85	11	−04	06	15	02	08	−20	−04	04	−01	−03	19	10	00	06	14
Sideslip Error Score	6	86	09	03	08	05	−05	18	−01	−06	−07	04	−10	27	01	03	05	15
Sideslip Error Score	7	87	05	05	06	01	−03	25	14	−04	−02	−01	00	18	11	−03	18	17
Sideslip Error Score	8	88	11	−05	08	02	15	20	17	−03	00	06	04	22	−04	01	16	19
Sideslip Error Score	9	89	12	−01	12	−03	12	07	17	−02	05	08	09	19	14	15	26	24
Sideslip Error Score	10	90	03	10	05	−11	13	16	10	−12	−05	05	−01	19	11	−01	24	20
Time-On-Target Score	1	91	22	06	00	05	15	08	05	01	−16	−01	02	13	12	−21	−03	19
Time-On-Target Score	2	92	11	08	01	03	05	06	10	−01	05	09	05	11	09	−08	08	08
Time-On-Target Score	3	93	17	12	03	−01	04	07	21	−01	−07	08	07	12	−02	00	06	13
Time-On-Target Score	4	94	19	08	−02	−01	17	−01	18	10	03	07	03	07	00	−18	09	17
Time-On-Target Score	5	95	30	14	−01	02	06	02	25	17	−04	06	−02	−05	00	−07	21	26
Time-On-Target Score	6	96	27	12	04	05	15	10	10	00	−01	17	03	13	11	−07	19	23
Time-On-Target Score	7	97	19	10	05	−04	10	13	12	−04	04	04	10	08	07	−06	23	17
Time-On-Target Score	8	98	17	02	11	−06	08	18	15	02	05	11	13	20	03	−02	22	23
Time-On-Target Score	9	99	17	03	07	−03	16	14	15	−02	−01	04	07	27	11	12	21	25
Time-On-Target Score	10	100	25	05	03	−05	19	17	−03	−19	−08	06	06	13	16	05	30	31

Note.—Decimal points have been omitted.

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